REPORT OF SURVEY CONDUCTED AT

DEPARTMENT OF ENERGY,
OAK RIDGE OPERATIONS
OAK RIDGE, TN

NOVEMBER 1996

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Best Manufacturing Practices

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Foreword

This report was produced by the Best Manufacturing Practices (BMP) program, a unique industry and government cooperative technology transfer effort that improves the competitiveness of America's industrial base both here and abroad. Our main goal at BMP is to increase the quality, reliability, and maintainability of goods produced by American firms. The primary objective toward this goal is simple: to identify best practices, document them, and then encourage industry and government to share information about them.

The BMP program set out in 1985 to help businesses by identifying, researching, and promoting exceptional manufacturing practices, methods, and procedures in design, test, production, facilities, logistics, and management – all areas which are highlighted in the Department of Defense's 4245-7.M, *Transition from Development to Production* manual. By fostering the sharing of information across industry lines, BMP has become a resource in helping companies identify their weak areas and examine how other companies have improved similar situations. This sharing of ideas allows companies to learn from others' attempts and to avoid costly and time-consuming duplication.

BMP identifies and documents best practices by conducting in-depth, voluntary surveys such as this one at the Oak Ridge Operations, Oak Ridge, Tennessee conducted during the week of November 4, 1996. Teams of BMP experts work hand-in-hand on-site with the company to examine existing practices, uncover best practices, and identify areas for even better practices.

The final survey report, which details the findings, is distributed electronically and in hard copy to thousands of representatives from government, industry, and academia throughout the U.S. and Canada – *so the knowledge can be shared.* BMP also distributes this information through several interactive services which include CD-ROMs, BMPnet, and a World Wide Web Home Page located on the Internet at http://www.bmpcoe.org. The actual exchange of detailed data is between companies at their discretion.

Since its original survey in March 1993, Oak Ridge Operations continues to advance in quality, excellence, and research. In addition to these goals, its new mission promotes communication, marketability, and collaboration with the private sector. This spirit of change continues to characterize Oak Ridge's activities as it builds on its historic strengths; delivers scientific and technological value; and establishes itself as an efficient, cost-effective complex regarded for its high excellence, ethics, and integrity. Among the best examples were Oak Ridge's accomplishments in mass spectrometry; electrical signature analysis; virtual capabilities; non-surgical cancer diagnosis; Oak Ridge Centers for Manufacturing Technology; Manufacturing Skills Campus; and Ultraprecision Manufacturing Technology Center.

The Best Manufacturing Practices program is committed to strengthening the U.S. industrial base. Survey findings in reports such as this one on the Oak Ridge Operations expand BMP's contribution toward its goal of a stronger, more competitive, globally-minded, and environmentally-conscious American industrial program.

I encourage your participation and use of this unique resource.

Ernie Renner
Director, Best Manufacturing Practices

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Section 1

Report Summary

Background

In the 1940s, Oak Ridge Operations was established as one of the primary sites for World War II's Manhattan Project. Today, the U.S. Department of Energy complex has expanded far beyond its original mission and supports various activities such as major energy research and development programs; dismantlement and storage of nuclear weapon components; emergency manufacturing; design, fabrication, and certification of precision prototype hardware and assemblies; environmental management; educational training; and manufacturing technology transfer programs. Located in the city of Oak Ridge, Tennessee, Oak Ridge Operations encompasses 35,252 acres of land and embraces three primary research and technology facilities (Oak Ridge National Laboratory, Oak Ridge Y-12 Plant, and East Tennessee Technology Park) as well as supportive organizations.

Operated by Lockheed Martin Energy Research Corporation, the Oak Ridge National Laboratory conducts applied research and engineering development to advance the Nation's energy resources, environmental quality, scientific knowledge, educational foundations, and industrial competitiveness. The site covers 2,900 acres and employs 5,000 personnel. Its fiscal budget was $672 million in 1995.

Operated by Lockheed Martin Energy Systems, Inc., the Oak Ridge Y-12 Plant provides weapon components dismantlement; highly-enriched uranium storage and management; nuclear weapon stockpile support; environmental restoration; waste management activities; precision manufacturing; and national security programs. The site covers 811 acres and employs 4,000 personnel. Its fiscal budget was $545 million in 1995. The Oak Ridge Centers for Manufacturing Technology, also located at Y-12, provides manufacturing technology transfer programs that are available to the Nation's private sector as well as other federal customers.

Also operated by Lockheed Martin Energy Systems, Inc., the East Tennessee Technology Park provides leading-edge research, development, and implementation of environmental restoration and waste management technologies related to monitoring, handling, decontaminating, decommissioning, treatment, and storage. The site covers 1,500 acres and employs 4,000 personnel. Its fiscal budget was $316 million in 1995.

Oak Ridge Operations, like other government facilities, currently faces changes, challenges, and opportunities related to changing missions and declining budgets. Clearly the facilities, infrastructure, capabilities, and expertise that exist at Oak Ridge are world-class and generally unequaled. Among the best practices documented were Oak Ridge's mass spectrometry; electrical signature analysis; simulation technologies; non-surgical cancer diagnosis; Oak Ridge Centers for Manufacturing Technology; Manufacturing Skills Campus; and Ultraprecision Manufacturing Technology Center.

Mass spectrometry remains one of the world's most widely-used analytical techniques. Recognized as the world leader in this field, Oak Ridge has improved this technology by reducing the equipment cost and size, and by automating the analysis capabilities. These improvements promote field usage by allowing the technology to be portable, providing real-time analysis, and permitting laymen to operate the equipment efficiently.

Traditional electric motor and generator test methods of analyzing load and performance with total current and power monitoring cannot provide the high resolution needed to describe evolving faults or small variations in the applied loading. Oak Ridge developed several signal conditioning and signature analysis methods that exploit the intrinsic abilities of conventional electric motors and generators to act as transducers. By using current and voltage probes, electrical signature analysis detects and analyzes the small time-dependent load and speed variations generated within an electro-mechanical system and converts them to frequency signatures which are useful for both mechanical and electrical fault detection.

Oak Ridge's capabilities in the area of simulation technologies include integrated concurrent engineering environments, a virtual factory, and a machine tool training simulator. Through the Concurrent Engineering Center, Oak Ridge can develop, visualize, and analyze proposed designs on a 3-D computer model under simulated conditions prior to the fabrication of a prototype. Oak Ridge's virtual

factory simulates a discrete and continuous factory which not only offers layout capability but features production cycle-time predictions and human ergonomic models for design. Oak Ridge's machine tool training simulator provides users with hands-on operating experience, real-time feedback, and the capability to train in a realistic environment by exposing the user to a virtual fabrication shop.

Conventional methods of biopsy diagnosis require a tissue sample and usually a lengthy turnaround period for laboratory analysis. Oak Ridge has developed a laser-based, non-surgical method for diagnosing cancer. This differential normalized fluorescence procedure uses a fiber-optic endoscope, requires no tissue sample during the procedure, and provides immediate diagnostic results. Clinical evaluation of this technique has proven it to be almost 100% accurate when diagnosing esophageal cancer.

Oak Ridge serves the Nation through the Oak Ridge Centers for Manufacturing Technology by maintaining core competencies related to weapon manufacturing, providing access to user facilities, operating the manufacturing skills campus, and providing opportunities via technology transfer programs. Success results by combining the overlapping research and development capabilities of the Oak Ridge National Laboratory, the unique manufacturing technologies of the Y-12 Plant, and the environmental restoration experience of the East Tennessee Technology Park.

As the training arm of the Oak Ridge Centers for Manufacturing Technology, the Manufacturing Skills Campus offers intense hands-on and performance-based training courses for government, industry, and academia. The Campus features national broadcasts on industry-relevant topics via remote electronic hook-up, and a virtual training model which reduces traditional cost and schedule barriers.

As new technologies produced a need for smaller, more precise components, the demand for machining capabilities with submicron tolerances increased. Oak Ridge's Ultraprecision Manufacturing Technology Center provides fabrication methods and precision metrology with submicron tolerances. In addition, the Center specializes in ion milling; single-point diamond turning; ductile grinding; and miniature/micro optical systems.

Since its original survey in March 1993, Oak Ridge Operations continues to advance in quality, excellence, and research. In addition to these goals, its new mission promotes communication, marketability, and collaboration with the private sector. This spirit of change continues to characterize Oak Ridge's activities as it builds on its historic strengths; delivers scientific and technological value; and establishes itself as an efficient, cost-effective complex regarded for its high excellence, ethics, and integrity. This BMP survey report should not be considered as superseding the March 1993 report, but should be viewed as complementary to the first report. The practices documented as Best Practices in the March 1993 report have not been replicated in this report, but are still considered to be Best Practices. The BMP survey team considers the following practices to be among the best in industry and government.

Best Practices

The following best practices were documented at Oak Ridge:

Information

The following information items were documented at Oak Ridge:

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Intelligent Welding — **62**

Current work at Oak Ridge Centers for Manufacturing Technology focuses on Intelligent Welding which integrates the inspection into the manufacturing welding process. By using a real-time assessment of the welding process and enacting the feedback control techniques, the end product's quality can be improved.

Laser Radar — **62**

By combining range imaging technology with amplitude-modulated laser radar technology, Oak Ridge National Laboratory has developed a method for measuring the arc lengths along complex, body surface contours. This innovation utilizes active laser ranging equipment, combined with mirrors and calibration, and image analysis procedures.

Machining and Inspection Research User Center — **63**

The Machining and Inspection Research User Center comprises nine separate laboratories and offers researchers an opportunity to work with experienced personnel, state-of-the-art facilities, and high-precision grinding equipment. Capabilities include high-temperature material manufacturing; complex ceramic component grinding; wear and friction studies on lubricants; material removal rate evaluation; wheel characteristic investigation; and use of modulus-of-rupture bars for basic grindability studies.

Micro-Metrology — **63**

Oak Ridge's Ultraprecision Manufacturing Technology Center has developed a unique capability for performing dimensional metrology of micro-fabricated components. This capability uses techniques such as stylus profilometry, modified video microscopy, and optical interferometry to accurately assess the dimensional variations within micro-fabricated structures.

Nickel-Aluminum Bronze Casting — **63**

Oak Ridge Centers for Manufacturing Technology has developed a nickel-aluminum bronze casting process which can create quick, practical, high-quality, 1/4-scale castings. The process eliminates or minimizes dead parts, weld repairs, machining probes, setups, and inspections.

Item — **Page**

Recycle Products Purchasing Plan — **64**

In response to the Federal Acquisition, Recycling, and Waste Prevention Order, Lockheed Martin Energy Systems and Lockheed Martin Energy Research started several proactive initiatives to improve its facilities' recycled product purchases. Between 1990 and 1995, total purchases toward the EPA-designated categories in the Resource Conservation and Recovery Act, Section 6002 rose from 6% to 38%.

Silicone Rubber Fiber Optics — **64**

Oak Ridge Centers for Manufacturing Technology has been using a new class of optical fibers called silicone rubber fiber optics in many sensor development programs. Fabricated from a silicone elastomer, these optical fibers feature a remarkable elasticity which allows the fiber to be tied into knots, stretched to twice its original length, or compressed from its normal circular profile into an ellipse.

Thermal Spray Development — **65**

Oak Ridge Centers for Manufacturing Technology's Thermal Spray Technology Center features experienced personnel, state-of-the-art facilities, and thermal spray equipment. Thermal spray capabilities provided by the Center range from corrosion coatings to near-net shape component development.

Traced Oralloy Casting Advisor — **65**

Oak Ridge Centers for Manufacturing Technology is developing a Traced Oralloy Casting Advisor system which will preserve the skills and knowledge of top casting experts in the area of depleted uranium. Oak Ridge Centers for Manufacturing Technology expects this system to reduce the time, cost, and training requirements associated with making accurate castings.

Advanced Command Post Project — **65**

Oak Ridge was tasked by the U.S. Army to define, develop, and deploy an effective and reliable communications system for the warfighting commands. Studies for the Advanced Command Post Project included large screen displays, terrain visualization, erectable antennae, and transportable shelters.

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Joint Flow and Analysis System for Transportation	**70**

In 1989, Oak Ridge developed the Joint Flow and Analysis System for Transportation as a multi-modal transportation analysis model for the U.S. Transportation Command and the Joint Planning Community. This model performs fort-to-foxhole modeling of military deployments on an international level.

Optical Time Domain Reflectometry-Based Active Seal System	**71**

Containers that store nuclear material must periodically be examined to ensure that their seals (tamper indicating devices) have not been broken. Oak Ridge has developed an optical time domain reflectometry-based active seal system to minimize the labor, time, and radiation-exposure aspects associated with seal inspections.

Engineers and the Shop Floor Course	**71**

Of all the courses offered by the Manufacturing Skills Campus, the Engineers and the Shop Floor Course offers engineers and managers one of the most unique training opportunities. Participants can enhance their knowledge and skills by gaining hands-on experience in an advanced manufacturing shop floor environment.

Intelligent Advisors	**71**

Oak Ridge began examining intelligent advisor systems as a means to capture and preserve the knowledge and skills of its experts. These systems rely on the integration of models, executable data, and graphics; a software development environment; and a knowledge architecture.

Law Enforcement Computer System	**71**

In June 1996, Oak Ridge Centers for Manufacturing Technology reviewed the Tennessee Corrections Department's computer system for processing criminal information history. To improve the state's current database, Oak Ridge Centers for Manufacturing Technology developed an electronic management system for compiling, retrieving, processing, storing, and tracking information on convicted criminals throughout the State of Tennessee.

Item	Page
Payroll, Absence, and Labor System	**72**

Oak Ridge developed the Payroll, Absence, and Labor System to consolidate its electronic collection systems, eliminate time cards, and provide a user-friendly interface for the user. The system is a multi-platform client/server application that provides the user with an open architecture.

Preventive Optimization Program	**72**

Oak Ridge Centers for Manufacturing Technology has developed the Preventive Optimization Program which maintains essential structures, systems, and components by using a Reliability Centered Maintenance philosophy. As an effective equipment reliability tool, the program analyzes failure modes, uses performance indicators, and identifies primary characteristics for the safe operation of a facility.

Procurement Re-engineering	**73**

By applying re-engineering techniques, Oak Ridge National Laboratory has simplified its procurement processes with positive results. The Procurement Department focused on five re-engineering initiatives: leadership and planning; information analysis and business results; human resources development and management; customer focus; and process management.

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Section 2

Best Practices

Design

Advanced Plasma Cleaning

Oak Ridge National Laboratory (ORNL) developed plasma sources which can produce ions (e.g. argon, hydrogen, helium, nitrogen, oxygen), multicharged ions (e.g. argon, nitrogen, oxygen), and neutral particles (e.g. oxygen, nitrogen) for cleaning wafers and aluminum samples. This technology eliminates the use of hazardous chemicals. In addition, ORNL developed optimal cleaning rates by controlling the particle energy, gas pressure, plasma source gas, and input power.

ORNL's experimental data shows that a 70%-oxygen/30%-argon plasma source cleans samples two to three times faster than a pure oxygen plasma source. The cleaning rate was measured as fast as 2.7 micrometers per minute. Although samples with a 200 volt RF-biasing can be cleaned without etch damage, samples with a 75 volt DC-biasing tend to show etch damage on the surface after cleaning. ORNL's study determined that plasma cleaning can be accomplished without etch damage by using the proper gas pressure, bias potential, and plasma source gas. Potential applications for this technology are plasma ion implantation, plasma cleaning, and plasma coating.

Centrifuge Pellet Accelerator

ORNL developed a centrifuge pellet accelerator system which can clean and strip without the use of solvents. Instead, the system uses CO_2 pellets to reduce waste, minimize damage to the item being cleaned, and enhance the cleaning performance.

The centrifuge pellet accelerator (Figure 2-1) system has many advantages over a compressed air system. The centrifuge pellet accelerator system is portable, contains no oil contaminants, and does not require hoses or air compressors. By reaching speeds of over 450 meters per second, the CO_2 pellets enhance the cleaning and stripping processes. Narrow velocity spreads make the velocity more controllable which creates a uniform process and reduces possible damage by eliminating pellets that are too fast and pellets that are too slow to effectively perform the task. In addition, the centrifuge pellet accelerator system only needs a 15 hp motor to accomplish the same job as a 150 hp compressed air system.

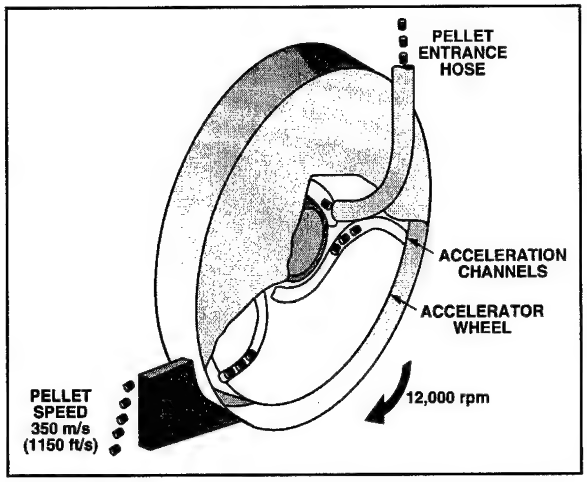


Figure 2-1. Centrifuge Pellet Accelerator

ORNL has successfully demonstrated its centrifuge pellet accelerator system in the following applications: cleaning plastic molds; cleaning industrial textiles without damage; cleaning diamond impregnated grinding wheels; removing epoxy paint from F-15 aircraft skin; removing oxide layers from various metals; deburring small stainless steel tubing; and the controlled deformation of large aluminum sheets. Presently, the centrifuge pellet accelerator system works more efficiently in high temperature environments versus low temperature environments which could limit its versatility. However, in controlled environments, the system performs at a world-class level and has potential applications in many industries. These applications include paint stripping, cleaning, decontamination, surface preparation, deburring metal surfaces, and cleaning plastic molds.

Controls Research Engineering Workbench

The design/development of software controls or logic for mechanical, thermal, and fluid systems can be a detailed, iterative process. At times, this

control system development process may slow down the test and production stages, or hamper the optimal operation of the end product. To improve the process, the researchers at ORNL developed a portable, turnkey system called Controls Research Engineering Workbench (CREW). The CREW workstation (Figure 2-2), a Pentium-based laptop computer, uses advanced control system simulation, analysis, and design software to design and troubleshoot control systems. Its major advantage is its portability. The entire system can be stored in a suitcase and carried by one person to the customer's site to solve industrial control problems.

Previously, control-system designs tended to use classical theory descriptions such as Bode, Nyquist and Root Locus. Implementation with actual systems often required the tuning of a proportional-integral-differential feedback loop during the development process. Additionally, the lack of prototyping methods for manufacturers prevented the use of many new techniques currently available.

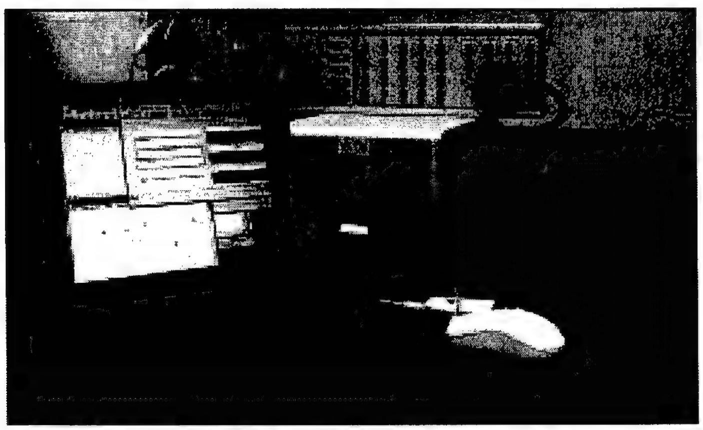


Figure 2-2. CREW Workstation

By using comprehensive, integrated software and hardware tools, the CREW workstation provides a unified approach to control system research and development. The workstation bridges the gap between automated control system practices, classical theories, and modern theories through its modeling and simulation; system identification; symbolic computation; control system analysis and design; hardware implementation of controllers; and in-situ validation of control strategies. The available control strategies include classical as well as modern methods of adaptive control, fuzzy logic, and neural networks. The CREW workstation consists of an embedded, digital signal processor with analog and digital input/output, and control engineering software which runs on a standard laptop computer. The developers at the Oak Ridge Centers for Manufacturing Technology (ORCMT) incorporated many commercial-off-the-shelf (COTS) software packages, allowing for mathematical and block diagram representation of the system; exercise of control parameters; and creation of C-programming code for specific applications.

The CREW workstation has many advantages over current control system development processes. Portability and decreased design/development time produces time and labor savings. The CREW system encourages the use of sophisticated control algorithms which improves product quality, control precision, and operational performance. Applicabilities for the CREW workstation include the steel, automotive, semiconductor, chemical, paper, metal casting industries, and electric power plants.

Healthcare Information Technologies

The healthcare community trails far behind other industries in its use of standardized information systems technology. Because health information systems are non-standard, fragmented, and often proprietary, they limit access and interoperability. Estimates reveal that healthcare professionals spend almost 40% of their time on paperwork, usually searching for critical information. Frequently, decisions must be made without the benefit of the latest information in real time. In addition, the demand to control spiraling healthcare costs while enhancing and broadening access to care drives many healthcare technology initiatives. The challenge lies in determining which technologies meet current or emerging requirements; how to integrate and protect the system and its information; and how to make the resulting applications useful and accessible to the user community.

Lockheed Martin Energy Research's (LMER's) Data Systems Research and Development (DSRD) program participates in or leads several key projects in healthcare information technologies. Two projects include the Healthcare Information Infrastructure Technology (HIIT) and the Healthcare Information Technology Enabling Community Care (HITECC). Both projects are funded by the National Institute of Standards and Technology (NIST) Advanced Technology Program and co-sponsored by the Healthcare Open Systems and Trials (HOST)

consortium. The HOST consortium's mission is to improve healthcare (cost, quality, and access) through the widespread deployment of open, interoperable, standardized, and secure healthcare information systems. The team participating in these projects consists of leading companies in the information technology industries; major healthcare organizations; and public and private research institutions. The DSRD program provides overall technical leadership; demonstrates proof-of-concept with enabling technologies that use rapid-prototyping environments; and develops and implements technology testbeds.

The HIIT project will enable a virtual healthcare environment. By providing the necessary information tools, HIIT can dramatically improve the availability of healthcare information and the use of healthcare resources via electronic commerce, shared vocabulary, work flow, and complex query tools.

The HITECC project is developing and demonstrating information mechanisms needed to change fragmented electronic and paper-based healthcare data into a community-wide, computerized information resource which provides secure and simple access to integrated, multimedia information across local and wide area networks. Communications; information security; and storage and retrieval of images comprise the three major aspects of HITECC.

The HIIT and HITECC projects are developing new tools for healthcare information technology utilization and management. The DSRD program contributes to these projects through such capabilities as telecommunications and networking technologies; information security; image processing; modeling and simulation; biotechnologies; standards application and development; and validation and verification via independent testbeds and technology assessment. Much of this work demonstrates potential use for military healthcare applications. In addition, the DSRD program functions in a leadership role to bring together unique capabilities for identifying problems; and developing and testing proof-of-concept prototypes that support Department of Defense (DOD) needs.

The potential broad-based economic benefits of projects like this are staggering. For example, HITECC offers solutions which could provide up to $1.5 billion in healthcare savings. Nationally, healthcare costs consume approximately 14% of the U.S. GDP and are rising each year. As of 1994, the U.S. GDP was estimated at more than $1 trillion annually. The rising healthcare costs produce a negative impact on the U.S. economy in terms of jobs, quality of life, small business viability, and global competitiveness. Considerable savings could be realized if the burden of handling material and information was reduced through the re-engineering and automation of these tasks.

In addition, HITECC offers potential healthcare savings in three main areas: Integrated Multimedia Functionality (IMF), Community-wide Secure Information Sharing (CSIS), and Collaborative Computing (COLLAB). Table 2-1 shows a breakdown of these areas regarding technology applications, productivity enhancement, and projected benefits.

Table 2-1. HITECC Potential Healthcare Savings

TECHNOLOGY APPLICATION	PRODUCTIVITY ENHANCEMENT	PROJECTED BENEFITS
IMF		
Automated Voice/Text	Automated Transcription	$300M per year savings
Integrated Data/Consults	Geographic Integration	$450M per year savings
Multi-media Integration	Coherent Information	$75M per year savings
CSIS		
CHIN Enablers	CHIN Implementations	$250M per year savings
Security Automation	Reduced Fraud/Abuse	$300M per year savings
COLLAB		
Rural Pathology	Continuous Staff Utilization via Remote Telepathology	$100M per year savings

Information and Advisory System Testbed

In 1992, the Development Division at the Oak Ridge Y-12 Plant implemented an Information and Advisory System (IAS) testbed. The testbed is a state-of-the-art, software-development facility for the construction, evaluation, and demonstration of IAS solutions such as intelligent design and process advisor systems. The IAS testbed supports rapid prototyping of complex solutions by improved methods of integrating, presenting, analyzing, and communicating information to the end user. When used to develop design and process advisor systems, the IAS testbed reduced the software-development time and cost by 90%.

The traditional, software-development process begins with a detailed, functional-requirements document and progresses through a software-code development and test period of 6 to 36 months. Next, the end user reviews the prototype software, determines any new requirements, and the process is repeated. With the IAS testbed, the Development Division uses a new, software-development paradigm which produces the prototype software within a few weeks. This new process begins with an idea or basic concept, and quickly generates the prototype software that has user-driven system features. In addition, the process provides a needs-based migration path for maturing the system.

The IAS tools include databases, graphical data, and knowledge bases. These tools use the IAS software-development environment to develop an integrated system including product design and manufacture; material utilization; business decisions; operations; resource and asset management; and software hooks to all data structures. The core software, a powerful 3-D information and database tool, is provided by the Intergraph Geographical Information System (GIS). The GIS system integrates with the multi-layers of the Intergraph system to create a point-and-click, user-friendly interface for interactive graphics and information retrieval.

Advisory systems can be developed and applied to any application requiring key decisions. Examples include cost advisors for manufacturing; product design; process control; optimal production planning; integrated control; GIS information integration; business enterprise modeling; inventory control; intelligent facility management; asset management; flexible and concurrent engineering; and market studies and economic development.

Mass Spectrometry

Recognized as the world-leader in mass spectrometry, ORNL maintains a long history in fundamental and applied mass spectrometry dating back to the 1940s. Mass spectrometry remains one of the most widely-used analytical techniques. Applications include drug testing, crime-lab investigations, oil analysis, environmental studies, pharmaceutical research, and consumer protection. However, mass spectrometry can also be time consuming and expensive. The technology requires expensive, bulky equipment which hinders portability and real-time analysis for field personnel.

ORNL has been improving its mass spectrometry technology by reducing the equipment cost and size, and by automating the analysis capabilities. These improvements promote field usage because the technology will be portable and allow for real-time analysis. Applications for this new technology include characterizing suspects at a crime scene by analyzing fingerprint components; non-invasive testing of individuals for diseases or substance abuse; rapid, accurate analysis of deoxyribonucleic acid (DNA) at a crime scene; and mobile monitoring of vehicle exhaust emissions.

One unique application for ORNL's mass spectrometry technology is forensic chemical analysis of fingerprints. ORNL scientists determined that the compounds on skin surfaces can identify individuals, detect medical conditions, and determine drug dosimetry. The scientists are now developing techniques to identify and measure these compounds for various uses in health and law enforcement. Advanced ion trap mass spectrometry, presently being developed, will provide chemical analysis of latent fingerprints. By identifying and quantifying the compounds on skin surfaces, law enforcement officials will be able to determine personal characteristics of suspects, such as gender and tobacco or cocaine use. Obtaining the target compounds directly from the fingertips would significantly reduce the typical turnaround times (days or weeks) presently needed by laboratories to screen blood and urine samples. In addition, ORNL is studying this process for possible use in non-invasive drug screening and disease diagnosis.

Motor Efficiency and Load Software

ORNL played a lead role in the Department of Energy's (DOE's) Motor Challenge program. Initiated in 1993, the Motor Challenge program promotes energy efficiency practices in motor-driven systems and challenges manufacturing companies to replace inefficient motors with efficient ones whenever economically possible. The Motor Master software, developed by ORNL, comprises a key component of the Motor Challenge program. The software consists of a catalog which lists motors, efficiency data, and pricing information. Organized in a database, the information also provides a list of options, in order of efficiency, for replacing a specific motor. In addition, the Motor Master software can evaluate the efficiency of a rewound motor versus a new one.

The Motor Challenge program operates a clearinghouse which handles hundreds of reports on the energy efficiency of electric, motor-driven systems, including pumps, fans, and compressors. Companies can obtain the information on these systems through the clearinghouse. The Motor Challenge program has also conducted 20 showcase demonstrations in industrial settings. ORNL performed an independent validation of energy savings achieved in the industrial projects.

In April 1996, the Oak Ridge Motor Efficiency and Load (ORMEL) software became available through the Motor Challenge program. The ORMEL software provides interactive modeling of motor performance for the user. The user enters the motor's measured speed, current, voltage, and power. The software then provides the motor's torque output and efficiency. ORNL is currently distributing the ORMEL software.

Non-Surgical Cancer Diagnosis

Researchers at ORNL began collaborating with the Thompson Cancer Survival Center in Knoxville, Tennessee to develop a laser-based, non-surgical method for diagnosing cancer. This diagnostic instrument, whose development began only four years ago, uses a fiber-optic endoscope, requires no tissue sample during the procedure, and provides immediate diagnostic results. Conventional methods of biopsy diagnosis require a tissue sample and usually a lengthy turnaround period for laboratory analysis.

Fluorescence of tissue for tumor diagnostics has drawn some interest in the medical community since the 1950s. With the advent of the laser, interest has been renewed and various research groups have demonstrated a potential method which uses laser-induced fluorescence (LIF) for tumor diagnosis. Researchers have based the LIF diagnostic method on the differential normalized fluorescence (DNF) procedure.

The DNF procedure produces a normalization process; an enhancement of small but consistent, spectral differences; and an improvement in the diagnostic accuracy. The diagnostic instrument consists of a fiber-optic endoscope with two sets of bundles. One set delivers a low-energy, pulsed laser light to the tissue. The other set collects the resulting fluorescent light and carries it to a photometric detector and computer to be digitized and stored for analysis. Signal intensity from the tissue determines its diagnosis. Normal tissue yields a more intense signal than malignant tissues. However, signal intensity may also depend on non-physiological factors such as tissue distance from the endoscope. To account for these factors, the diagnosis also relies on a spectral analysis method which highlights subtle differences between normal and malignant tissue.

Clinical evaluation of this new, non-invasive technique proves to be almost 100% successful with esophageal cancer. Currently, the procedure is being tested on cancerous tumors of the colon, cervix, lungs, and urinary bladder. U.S. patents are pending for the laser-based, non-surgical technology. In addition, ORNL has recently licensed this technology to two U.S. companies for cancer diagnosis.

Test

Advanced Propulsion Technology Center

ORNL established the Advanced Propulsion Technology Center (APTC) to study a wide variety of technologies related to the transportation industry. The APTC is a technology development, integration, and evaluation facility for new technologies in diesel, gasoline, and alternative fuel engines; new material usage; diagnostics and control; emission measurement and reduction; and efficiency enhancing techniques. The APTC houses four dynamometer stands ranging from 25 to 400 hp; numerous single and multicylinder diesel and spark ignition engines provided by industry; emissions measuring equipment; a high-speed data acquisition system; and optical diagnostics for internal temperature measurements. A chassis dynamometer is available nearby at the University of Tennessee.

Temperature measurements in internal combustion engines provide necessary information to help engine designers develop cleaner, more efficient engines. By using phosphor thermometry, the APTC accomplished in-situ thermal characterization of engine components. Specific successes from this non-contact temperature measurement technique include steady-state piston crown temperature measurements and transient intake valve temperature monitoring during cold start conditions.

APTC also developed the catalyst surface spectroscopy method. In-situ measurements of catalytic reactions provide invaluable data for catalyst development. To measure these reactions, the APTC invented an accessory for use with Diffuse Reflec-

tance Infrared Fourier Transform (DRIFT) spectroscopy which allows the collection of spectra from surfaces that are heated and exposed to different gases. Presently, the APTC is evaluating this procedure for potential usage in examining in-situ reaction mechanisms of No_x reduction.

The APTC continues to research new technologies. Current efforts include electrical signature analysis to detect, analyze, and correct unwanted changes in process conditions or abnormalities in electrical and electromechanical equipment; response and performance evaluations of catalytic converter materials based on the complex and dynamic nature of real-life engine exhaust; and development of a vehicle fuel consumption and emissions database for use in real-life traffic models.

Composites Manufacturing Technology Center

ORNL maintains the expertise and resources to research, develop, document, and manufacture new composite technologies that could be integrated and used by the composite industry. In addition, test and analysis capabilities are readily available for characterizing state-of-the-art composite material. As the leading authority for composite technology, ORNL's Composites Manufacturing Technology Center predicts material property behavior by correlating data with manufacturing processes. By coupling benchmarked design and analysis tools with material property databases and manufacturing processes, the Center produces composites with predictable quality and performance.

Through available resources, the Composites Manufacturing Technology Center developed and demonstrated prototype composite component structures. Composite evaluations include the validation and identification of mechanical properties, physical properties, and fatigue behavior. The composite components are also subjected to life-cycle stresses and non-destructive testing.

Through extensive research, the Center demonstrated that the electron-beam (EB) curing process as a non-thermal means for curing (cross linking) polymeric materials within seconds. Conventional means of using resin and catalysts require hours for curing. Besides reduced curing time, the EB process improves part quality and performance; reduces environmental, safety, and health concerns; and yields a cost savings of 25% to 50%.

The Composites Manufacturing Technology Center also provides composite manufacturing education and hands-on training. By capitalizing on this opportunity, companies can expand their composite manufacturing capabilities.

Gear Metrology

In 1992, a NIST-sponsored meeting discovered that no gear calibration services existed in the United States. American industries and government agencies had to rely on European services for gear calibration. U.S. research and education were also falling behind its foreign competitors. In response, ORCMT established the Gear Metrology Center. As an alliance between government, industry, technical societies, and academia, the Center provides a national infrastructure for gear measurements which are traceable to the international standard for length. The Center applies existing precision metrology, facilities, equipment, and expertise toward gear metrology needs.

The Metrology Center develops methodologies for artifact and master gear calibration; designs training courses in the proper use of calibrated artifacts; and participates in the correlation of measurements from various methods, equipment, and facilities. In collaboration with NIST, the Center offers the calibration of involute-profile master artifacts with a stated 95% uncertainty of $\pm$ 36 millionths of an inch. Calibration services for lead masters will be available by the end of 1996 and index masters, pin masters and master gears by the end of 1997.

With the establishment of ORCMT's Metrology Center, U.S. facilities can now receive traceable calibration service in the United States. Benefits of the Center include increasing rates, decreasing costs, eliminating overseas delivery, and supporting the U.S. economy by keeping the money within the country.

Infrared Surface Inspection

For more than 20 years, scientists at the Oak Ridge Y-12 Plant have collaborated with the private sector to develop methods for remotely analyzing surfaces, gases, and liquids by infrared and Raman spectroscopies. In addition, parallel research efforts have developed custom accessories and techniques for monitoring surfaces and thin films. Today, surface cleanliness can be certified with resolutions that are approaching one molecular layer.

Infrared inspection techniques for chemical analysis prove to be a significant advance in process control for the manufacture of reactive materials. Valuable attributes of these techniques include controlling environmental degradation of part surfaces, evaluating stains and surface cleanliness, and preparing surfaces for coatings and bondings. The ability to perform chemical analysis in a real-time manufacturing environment permits deterministic control of the production processes, minimizes waste and rework; and eliminates sample-based quality control.

Applications for infrared inspection techniques include:

- Evacuable cells for surface analysis by DRIFT spectroscopy — a method to characterize the uranium oxide surfaces; the reactions of lithium hydride with water vapor; the isothermal oxidation of coal; and the cure and oxidation of graphite-epoxy composites. This technology won the I-R 100 Award in 1984 and the R&D 100 Award in 1989.
- Spectropus™ — a system to measure the extent of lithium hydride reactions with moisture by the quantitative analysis of lithium hydroxide down to sub-nanometer film thickness. This system integrated DRIFT technology with state-of-the-art vacuum and gas handling facilities for total in-situ surface and gas analysis in highly controlled experimental environments.
- Inspector™ — a system to measure the mid-infrared spectra from flat or convex surfaces. This system was a further development that took advantage of, and built upon Spectropus System's exceptional light collection efficiency. It has allowed fabrication of compact, field portable devices.

The above represent only a small portion of exceptional applications developed in collaboration between Oak Ridge and private industry. Benefits from infrared inspection techniques include enhanced confidence in polymer composite materials used in air and space vehicles; increased reliable field inspection capabilities and methods; and reduced maintenance with improved reliability.

Motor Test Facility

What began a few years ago as an investigation of motor-driven valves at Oak Ridge developed into an in-depth, real-time, testbed for electric motors. The Motor Test Facility can emulate any combination of motor field conditions and provide the data acquisition and analysis capability for a thorough investigation of any motor design, manufacturing, or analysis problem. In addition, the facility can create the primary, field-service conditions which may produce a major effect on motor efficiency and motor lifetime. Such conditions include phase unbalance of voltage; undervoltage or overvoltage; structural resonance in the foundation; misalignment between motor and driven equipment; and load torque oscillation in the driven equipment. Currently, the Motor Test Facility is constructing a harmonic voltage distortion console which will emulate any combination of harmonics previously identified in service situations.

In the near future, the Motor Test Facility will house a complete research facility for three-phase industrial drive motors up to 2,000 hp and 6.9 kV. The test pedestal, designed to accommodate motors up to 100 hp, is operational and continues to expand on its proven track record. Special "soft feet," located in the base-plate channels, isolate the motor from external vibrations. The test pedestal also accommodates a 150-hp, water-cooled, eddy-current dynamometer; a 20 kV generator; a 1-hp generator to serve as loads; and a 140-amp, three-phase variac. Each phase of the variac can independently be adjusted from 0% to 120%.

The Motor Test Facility provides laser alignment capabilities for motors to ensure exact alignment or to study the effect of misalignment. The facility also supplies complete failure analysis equipment so a faulty motor can be disassembled and analyzed to confirm its root cause of failure.

Optical Metrology

Optical diagnostics offer industrial advantages for today's challenging environments. Optical measurements require no contact with the unit under evaluation, use non-invasive measurements, furnish high resolution over a wide range, and provide multiple measurement strategies. In addition, optical measurements prove to be useful in areas of limited access or where contact could create difficulties.

ORNL's Center for Manufacturing Technology Metrology offers a wide variety of technologies for optical diagnostics. The Center illustrates its expertise by deploying measurement systems into challenging environments. Optical applications, developed by ORNL, exist in today's industries for use with interferometers, holographs, and laser micrometry.

ORNL developed interferometric applications for manufacturing environments, steam-powered generating stations, and high resolution laboratory measurement systems. One method uses interferometry to monitor the amount of moisture contained in steam which is directly related to the efficiency and safety of steam-powered generation stations.

Holographs provide a reference point for subsequent images at submicron accuracy. The Center can provide and store real-time data for comparing and measuring mechanical or thermal stresses by using an integral vision system. Provided with technical expertise from ORNL, Diffraction International evaluated and resolved any problems with the Computer Generated Hologram (CGH) null adapter prototype. This led to the successful introduction of a commercial CGH null adapter. By using standard commercial equipment, this adapter can provide an accurate and less-expensive means for testing aspheric-optical surfaces. ORNL now provides optical metrology technology and expertise for measuring and testing precision, aspheric-optical surfaces with CGH null adapters.

ORNL developed a laser micrometry method which simultaneously measures the size and weight of a ceramic component as it dries. This method provides a high resolution record of component drying characteristics. Through its laser micrometry research, ORNL showed that the manufacturing ceramic baking time (for curing) can be shortened without degrading component reliability.

Precision Metrology

In 1992, a NIST-sponsored meeting discovered that no precision measurement services for large products existed in the United States. American industries and government agencies had to rely on European services for end standard and step gauge calibrations. In response, ORCMT established the Metrology Center. As an alliance between government, industry, technical societies, and academia, the Center provides a national infrastructure for end standard and step gauge measurements which are traceable to the international standard for length. The Center applies existing precision metrology, facilities, equipment, and expertise toward precision measurement needs.

The Metrology Center combines its advanced technological capabilities with NIST's measurement expertise, and features a high-precision, large-volume Moore M60 coordinate measurement machine. The Center can calibrate end standards and step gauges up to 1.35 meters long to a certified accuracy of 0.7 micrometers per meter (equivalent to one-hundredth the diameter of a human hair) which exceeds NIST's previous maximum of 750 millimeters. Though varying in appearance and composition, step gauges resemble long rulers with precisely determined total and incremental lengths. For end standards, only the length is calibrated.

Among its many calibration disciplines, ORCMT's Metrology Center also offers precision mass measurements. As a world-class weight calibration laboratory, the Center provides highly accurate measurements and calibrations which are traceable to the international standard for weights. The Metrology Center's calibrating weight standards range from 1 milligram to 30 kilograms within Class I tolerances. Criteria for Class I tolerances are established by NIST and the National Voluntary Laboratory Accreditation Program. The Center also offers calibrations of 50 to 1,000 pound weights within Class II tolerances. Class II calibrations require a tighter tolerance for environmental controls and uncertainty reporting. The Metrology Center follows NIST guidelines for determining uncertainty calculations.

Presently, ORCMT's Metrology Center can provide calibrations up to 1.35 meters for one-dimensional end standards and step gauges. Plans call for extending the upper limit to 1.6 meters. As the Center's capabilities develop, precision dimensional services may be expanded to 2-D and 3-D measurements for calibrating large grid and ball plates. The Metrology Center also repairs and upgrades scales and balances. Scales with 0.001% accuracy have been successfully upgraded to 0.00005% specifications.

Radio Frequency Test and Evaluation Facility

Created through a contract with SEMATECH, the Radio Frequency Test and Evaluation facility evaluates and benchmarks radio frequency compo-

nents used in material processing. The facility established a record of industrial successes through its use of advanced, high-powered sensors; surrogate plasma loads; and modeling and testing techniques.

The Radio Frequency Test and Evaluation facility provides high-power capabilities (1 MHZ to 60 GHz); models for transmitters, matching networks, antennas, and nonisotropic materials; and precision test equipment (milliwatts to megawatts). In addition, the facility possesses extensive engineering and fabrication capabilities. Because of its expertise, equipment, and capabilities, the Radio Frequency Test and Evaluation facility can test and evaluate all aspects of a radio frequency system. Diagnostic capabilities include phase-locked network analyzers for impedance measurements; a vector spectrum analyzer for frequency and harmonic measurements; and calorimetry and electrical techniques for accurate and repeatable power measurements. In addition, radio frequency components can be evaluated as a function of power, impedance, and/or frequency.

The radio frequency/microwave technology has shown success in numerous commercial industries. The chemical processing industry can manufacture specialty glass and accelerate the drying of polymers, recycling sorbents, and SiO_x plasma deposition. The waste processing industry can vitrify low level waste and remove contamination from concrete surfaces. The paper industry can enhance the removal of lignon. The ceramics industry can sinter and anneal armor tiles. The semiconductor industry can process plasma.

The Radio Frequency Test and Evaluation facility also has several potential applications for military purposes. These include test and evaluation of communication and radar systems; and plasma processing for manufacturing computer chips and flat plate panel displays.

Oak Ridge is a recognized leader of radio frequency/microwave technology in the semiconductor processing industry and in the international magnetic-fusion effort. The Radio Frequency Test and Evaluation facility represents one of the premier facilities in the United States because of its broad range of frequency, power, and diagnostic capabilities.

Remote Microscopy

ORNL's High Temperature Materials Laboratory (HTML) promotes remote-site use of its state-of-the-art microscopy equipment. This virtual laboratory provides a simple and inexpensive way to access electron microscopy via the Internet or through ISDN lines.

Through HTML's remote microscopy capabilities, users can analyze and characterize microstructures for changing applications, improving manufacturability, and determining mechanisms that result in structural changes during testing. Examples of HTML's microscopy equipment include:

- Transmission Electron Microscopy performs microstructure, phase identification, and nanometer scale composition.
- Scanning Electron Microscopy and Scanning Auger Microprobe perform surface morphology, nanometer scale surface composition, and micrometer scale subsurface composition.
- Scanning Probe Microscopy performs surface morphology and surface profilometry.

HTML personnel developed the necessary software and hardware for running the virtual laboratory by using the instrumentation controls from a personal computer. Because of this design, developers were able to perform the majority of the work on a scripting level which allows for easy expansion and debugging. Standard software was used for image recording and processing, along with standard interfaces on the microscope for the instrumentation control. The system works via remote through the commercial software called Timbukto Pro. Interested users can download the Timbukto Pro software by accessing the following address: ftp.farallon.com/pub/software/free_versions/TB2MEval2.0.sea.hqx

The virtual laboratory, presently on-line, allows $6 million worth of microscopy equipment to be available by remote access, including the Hitachi HF-2000 and the Hitachi S-4500. A website will be available soon at the following address: http://www.epm.ornl.gov/~geist/java/applets/uscope/.

Ultrasonic Material Acoustic Testing System

Over the years, the Oak Ridge Y-12 Plant has been actively involved in determining material quality by measuring the acoustic properties. Methods also evolved over the years from manual recording through resonance measurements to overlap techniques. However, the demand for a more accurate method of determining material quality led to the Ultrasonic Material Acoustic Testing (UMAT) system. Developed four years ago, this IBM PC-based workstation allows data to be analyzed more efficiently.

The UMAT system consists of a digital oscilloscope, a standard pulse/receiver, and a Pentium 90 PC. It runs in a LabWindows™/CVI environment and uses UMAT software. Written by the Y-12 researchers, UMAT software simplifies the process of making acoustic velocity measurements and calculating material properties. Unique features include automatic acquisition of two waveforms in the user's chosen windows; cross-correlation techniques to determine delay; spreadsheet format to display material property calculations (Figure 2-3); the ability to correct couplant, instrumentation, and diffraction errors; and the ability to handle multiple transducer configurations that are accurate to less than 50 picoseconds.

Upgraded in 1995, the UMAT system can now handle many different types of sample and transducer configurations, and can automatically calculate velocities and material properties. Material property measurements have been performed over the temperature range from -40°C to 1000°C, and have been characterized on metals, composites, ceramics, elastomers, liquids and plastics. The UMAT system significantly increases the capabilities of characterizing materials more accurately.

Weigh-in-Motion System

Total weight and weight distribution are two critical factors associated with the logistics of moving personnel and equipment. Oak Ridge's Weigh-in-Motion system uses portable weighing pads. The technology combines fiber optics and electronics, located within these pads, with weighing algorithms and calibration data. By driving aircraft and ground transportation vehicles over the weigh-

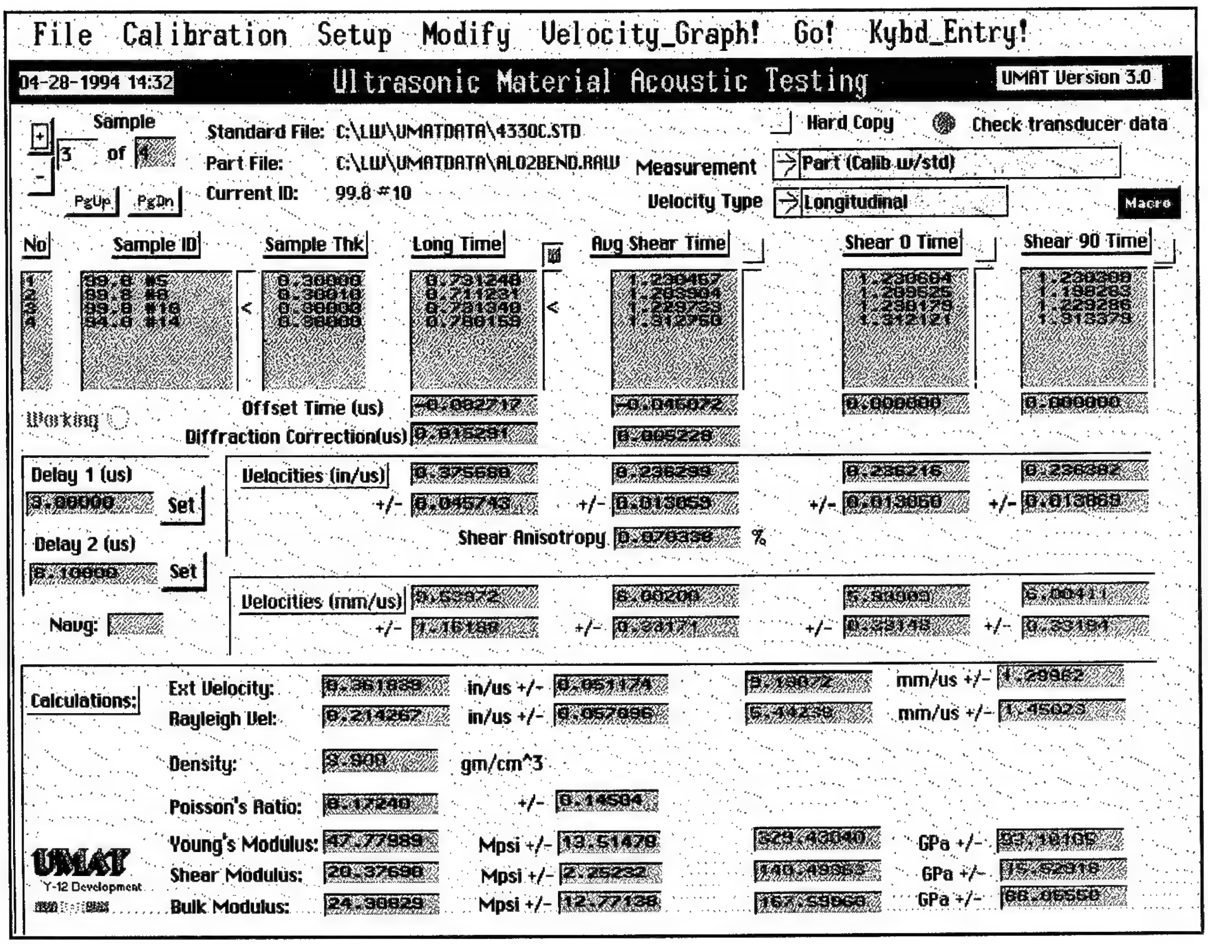


Figure 2-3. UMAT Spreadsheet Screen

ing pads, the system determines the total weight (accurate from 1% to 2%) and the weight distribution by axle or wheel (Figure 2-4).

The Weigh-in-Motion system is available through the ORCMT. Advantages include immediate determination of weight upon passing over the sensors; accurate and reliable technology; lightweight and portable system; modification of established technology; and minimal training for operation.

Weigh-in-motion technology has led to numerous applications such as self-weighing shelves, forklifts, and scrap buckets. In addition, tests currently under way in Knoxville, Tennessee predict the elimination of truck scales on highways. The technology could measure the weight of loads on forklift trucks and eliminate the need for stationary weighing. Fiber optics embedded in strands may enable this technology to weigh materials which are being loaded by crane or other lifting devices. Businesses would become more efficient at handling materials and realize significant cost savings.

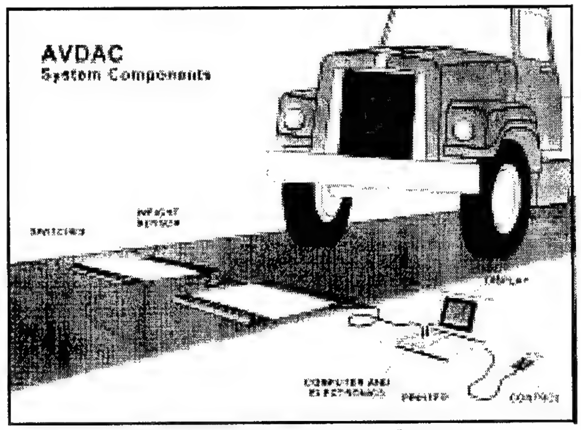


Figure 2-4. Weigh-in-Motion System

Production

Advanced Diagnostics and Condition-Based Maintenance

With declining budgets and rising maintenance costs, it is no longer sufficient to rely solely on predictive scheduling for servicing equipment and systems. The Department of Defense alone spends about $20 billion in maintenance activities. Maintenance costs are projected to rise as more fleet and weapons systems remain in-service for longer periods of time. Currently, Oak Ridge is developing numerous technologies in support of advanced diagnostics and condition-based maintenance concepts (Figure 2-5).

In 1994, Oak Ridge established the Process Diagnostics and Evaluation Center. The Center provides government and industrial partners with advanced, diagnostic technologies and integrated programs for monitoring and managing facilities. In addition, the Center operates through a technical-staff matrix which spans the various disciplines found at the Oak Ridge complex. Diverse diagnostic technologies, developed at Oak Ridge, are being focused through the Process Diagnostics and Evaluation Center, allowing for a broad range of manufacturing problems to be addressed. The Center can then establish predictive maintenance, condition-based monitoring, and machine health monitoring based on these diagnostic technologies.

In today's environment, the maintenance trend goes beyond scheduled preventive servicing. Instead, condition-based maintenance uses the current operational status of equipment to predict the life expectancy of components and systems. Condition-based maintenance evolved from the recent developments in inexpensive, more-powerful computer systems; advanced sensor systems; improved algorithms for data acquisition; and advanced methods for on-line signal processing.

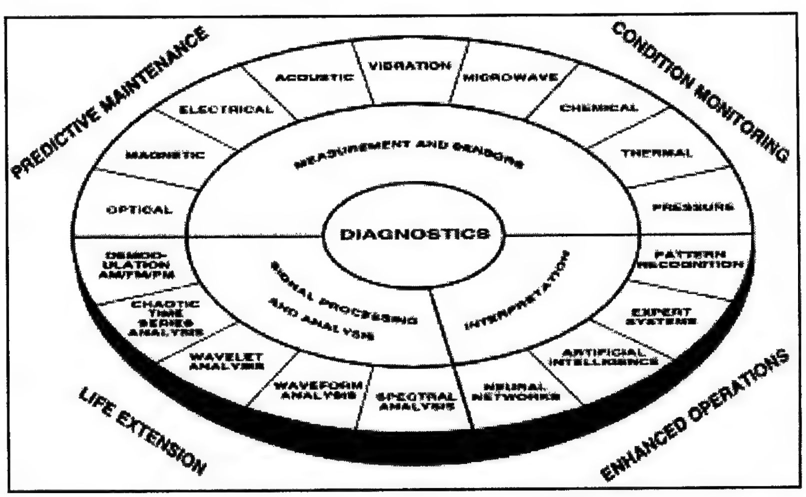


Figure 2-5. Oak Ridge Diagnostics Capabilities

Some diagnostic technologies which form the core of the Process Diagnostics and Evaluation Center's work include predictive maintenance techniques for facility management; electrical signature analysis; vibration signature analysis; acoustic signature analysis; nonlinear analysis of complex signals; photonic-based diagnostic techniques; fiber optic applications; weight measurements and weigh-in-motion technology; new materials for specialized sensors; and new sensor development and applications.

With condition-based maintenance, businesses will perform maintenance on an as-needed basis as soon as faults are detected. The technology will provide real-time feedback on the operational status of critical systems and relate performance to mission profiles. In addition, data collected from instrumented machinery can indicate performance status of other machines upstream or downstream in the chain. Overall, condition-based maintenance will reduce maintenance costs and improve system performance levels.

Advanced Oxidation Processes

A recently-completed Cooperative Research and Development Agreement (CRADA), involving the Oak Ridge Y-12 Plant, a surfactant producer, an ozone/ultraviolet equipment manufacturer, and a major university's environmental engineering department, demonstrated the merits of ozone/ultraviolet treatment of concentrated aqueous wastes which contain surfactants. The CRADA served as a practical evaluation of advanced oxidation processes (AOPs). These AOPs deal with enhancing the aerobic digestion of surfactants normally resistant to aerobic digestion.

The Clean Water Act of 1990 put surfactant and industrial users at significant economic and legal risk. Meeting wastewater discharge standards became difficult and expensive with conventional treatment methods. The United States consumes over 7.5 billion pounds per year of surfactant which is valued at more than $2 billion. While industrial processes consume about 45% of all surfactants, the remaining (55%) goes into consumer products. An improved waste management technology would allow surfactant manufacturers to increase production and meet wastewater discharge standards at reduced cost and liability.

AOPs use ozone, hydrogen peroxide, ultraviolet light, and catalysts (alone or in combination) to oxidize organic materials. Ozone, a powerful oxidant, has been used in Europe since 1905 to treat drinking and waste waters. However, its use in the United States is limited. The CRADA's goal was to integrate the AOPs with pollution prevention and conventional treatment methods. Specifically, it was to partially oxidize biorecalcitrant-surfactant molecules to intermediates that could be more easily removed through traditional aerobic digestion.

The advanced oxidation technologies, tested and demonstrated through the CRADA, are applicable to treating the highly-varied wastes generated by DOE's and DOD's facilities and laboratories. In addition, these technologies are pertinent in environmental restoration and waste management at these and other federal agency facilities. Advanced oxidation can destroy organic constituents in a wide variety of wastes while raising inorganic constituents to high oxidation states so the inorganic constituents can be predictably and repeatedly removed by conventional treatment processes.

Air Emissions Management System

The Clean Air Act, the Clean Air Act Amendments (CAAA), and the State of Tennessee's environmental regulators require detailed monitoring of industrial sites' emission points and air quality, and calculate the sites' annual fee based on the emission level. The intense-reporting and record-keeping requirements created a need for a multi-functional system to support CAAA.

A consolidated, verifiable, record-keeping mechanism did not exist prior to Oak Ridge's Air Emission Management System (AEMS). For each reporting activity, personnel manually searched through logbooks at each emission source, then consolidated the gathered data into Microsoft Excel, and finally calculated the appropriate emission levels and fees by manually comparing the data to allowable emission limits. Often, data was re-retrieved from emission sources for different reporting activities because the previously-collected data was difficult to cross-reference and multiple report preparers were not fully aware of which data had already been collected. This method created varying levels of data in the emission sources' and the source operators' logbooks; time-intensive work for report writers and facility operators to verify data; and calculation errors from manually analyzing the emission levels and fees.

LMER's DSRD group addressed these issues by holding user-sessions with the Oak Ridge Y-12 Plant personnel who provide the emission data.

After comprehending the users' processes, language, and data collection techniques, the DSRD group developed representative process models and data models. The Y-12 report writers and facility operators then verified that the models met the needs of all users. Next, the DSRD group further developed the models into an application which automated the users' requirements. Developed in compliance with a structured methodology, the models ensure that the software will be well documented, thoroughly tested, and under configuration control.

A core version of AEMS, which went on-line for users in April 1994, continues to evolve. This system reduced reporting errors by automating the calculations and comparisons. The time invested in report preparation decreased because data is now centrally located and easy to retrieve. In addition, the confidence level of the input data's accuracy increased.

As CAAA requirements continue to expand, the flexibility of AEMS is being tested. For example, ORNL's Title V, a comprehensive permit which will replace individual source permits, was not an original design parameter during software development. However, the AEMS data structure and functionality can easily be modified to support these new requirements. In addition, AEMS' capability will allow for a seamless transfer of air data from the mainframe to the Title V forms in a WordPerfect format. This ability will eliminate the need to enter data twice, reduce transcription errors, and allow the WordPerfect forms to become part of the Title V application.

The DSRD group developed AEMS in modules. This design allows the entire package or specific sections to be borrowed or expanded for other sites or for effective communication with other data systems.

Chlorofluorocarbon Phase-Out

Although the Montreal Protocol required chlorofluorocarbons (CFCs) to be phased-out of production by the year 2000, President Bush accelerated the requirement to December 31, 1995. Facilities across the Nation, including Oak Ridge's Y-12 Plant, needed to find suitable alternatives for chillers and other CFC uses. To meet these requirements, Y-12 proactively involved all levels of personnel in the decision-making process and established a plan for transition.

Previously, Y-12 had no monitoring program for leaks in its chiller systems nor used any stringent recycling parameters. In addition, no restrictions governed the purchasing or use of CFCs throughout the plant.

To initiate a transition, Y-12 started a training program involving CFC awareness; proper handling; recycle and recovery procedures; leak management; and alternative refrigerants. In addition, Y-12 established several CFC policies to define employee responsibility. CFC purchases were funneled through a central location where accurate inventories could be maintained. The employees maintained an assertive involvement in the CFC efforts through training, policy, and certification programs.

Y-12 also developed a long-term Stratospheric Ozone Protection Plan. This plan addressed retrofitting activities that reduced air emissions of CFC, such as installing high-efficiency purge units on low-pressure chillers, eliminating all chillers on-site that operated on five gallons or less of CFC, using portable refrigerant recyclers, and installing pressurization units on low-pressure chillers for leak detection. In addition, the plan included a large stock-piling effort which provided CFCs for use in chillers after the production ban went into effect.

Y-12 attributes its success in reducing CFC emissions to an aggressive conservation and recycling program which complies with Title VI of the Clean Air Act. In 1995, the plant reduced its CFC emission levels by 92% and its usage of solvents containing CFCs by 98%, compared to its 1992 figures. This program has won several awards and national recognition including the EPA's Stratospheric Ozone Protection Award in 1993, The White House's Closing the Circle Award in 1994, and DOE's Pollution Prevention Award in 1994.

The Y-12 Plant has consistently been a leader in CFC conservation and emissions reduction. In addition, Y-12 provides technical assistance to other DOE facilities and private-sector plants.

Energy Systems Laboratory Information Management System

In 1992, LMES managed five analytical laboratories: three in Oak Ridge, Tennessee (the Y-12 Plant, the East Tennessee Technology Park, and ORNL), one in Portsmouth, Ohio, and one in Paducah, Kentucky. Previously, each used its own nomenclature, test criteria, and information management system. Customers using these laboratories en-

countered multiple reports in multiple formats. In addition, each laboratory had varying levels of automation. Some used Ethernet and established networks while others had limited computing capabilities. Handling incoming samples also varied from site-to-site. Communication among the laboratories became impeded by the differing nomenclature even when discussing similar testing procedures.

To resolve this situation, the DSRD group developed a uniform, interactive system for the five analytical laboratories called the Energy Systems Laboratory Information Management System (ESLIMS). First, the DSRD group assisted the laboratories on standardizing the nomenclature, sample preparation, test requirements for specific analyses, and test turnaround times. Based on these standards, the DSRD group developed models. The laboratories then verified that the models met the needs of the users. Next, the DSRD group used the models to develop the programming code. Because of the diverse automation levels at the laboratories, the DSRD group developed both character and graphical user interfaces. The flexibility of the ESLIMS' data screens and tables allow each laboratory to customize the flagging, system default, and help functions for its entry person.

In use for more than a year, ESLIMS provides a cost-effective solution for achieving commonality across the analytical laboratories and for responding to changing business requirements. A cost/benefit analysis of the system estimated a savings of $1 million per year over a five-year period.

Environmental Monitoring Management Information System for Surface Water

Before the development of the Environmental Monitoring Management Information System for Surface Water (EMMIS-SW), the Y-12 Plant managed surface water data with various PC-based tools. Over the years, the data increased to over 10,000 samples per year and generated up to 30 results per sample. Staff could not handle the complex sample tracking requirements because of the increased volume of data. Resulting administrative errors created numerous permit violations for the plant. By using EMMIS-SW, Y-12 eliminated its sampling and analytical errors, and achieved zero permit violations.

EMMIS-SW, a suite of integrated software modules, supports the full-life cycle of surface water compliance and monitoring activities. The system checks all input data against reference tables for validity and integrity. EMMIS-SW supports field technicians and environmental managers with bar-code labels for sample bottles; accurate limit checking of samples against requirements; an electronic interface for transferring surface water data to external systems; and an electronic interface to the analytical lab system for submitting data and retrieving analytical results. Expanded from its original design, EMMIS-SW now automates the compiling and printing of the discharge monitoring reports by using Microsoft Access.

In use for more than three years, EMMIS-SW provides ease of use, flexibility, and report functionality. The system is now being adapted for use in the ORNL facility.

Head End Treatment System

LMES treats all process water for Oak Ridge's Y-12 Plant before it leaves the facility. Currently, the West End Treatment Facility processes 8 million gallons of water per year. During the water treatment, mixed sludge accumulates and is sent to the West Tank Farm (WTF) for storage in three 500,000-gallon tanks before final disposal. Approximately 40,500 gallons of mixed sludge accumulates annually during the water treatment process. At a cost of $1 million per tank, LMES needed a way to minimize the volume of radioactive sludge being transported off-site to a certified waste storage facility.

Mixed sludge contains various types of waste: common waste (acidic), basic wastewater (high concentrations of nitrates and heavy metals), and other waste (radioactive). Through additional steps, the Head End Treatment System (HETS) reduces the amount of radioactive waste by segregating the mixed sludge into radioactive sludge and non-radioactive, non-Resource Conservation and Recovery Act (RCRA) sludge. HETS removes heavy metals from the mixed sludge through hydroxide precipitation and neutralization of raw wastewater. The radioactive sludge is stored at the WTF while the non-radioactive, non-RCRA sludge ($CaCO_3$) can be recycled as a treatment chemical or sent to a land disposal.

Since implementation, HETS reduced operational costs at WTF from $9.5 million in 1993 to $4.3 million in 1995. In addition, the system reduced sludge generation by 30% (a portion of the regenerated sludge can now be readily disposed) and increased the storage life of the 500,000-gallon tanks from 12 years to 57 years.

High Speed Infrared Camera System

Typically high-speed infrared (IR) cameras perform non-destructive evaluations to look for subsurface oxide scales, cracks, delaminations, plugged cooling holes in turbine blades, and spallation (the separation of the thermal barrier coating in turbine blades). However, ORNL's High Temperature Materials Laboratory (HTML) developed a unique capability for its Amber high-speed IR camera. The speed and sensitivity of this camera allows, for the first time, quantitative thermal diffusivity mapping.

Other features of the Amber high-speed IR camera include a 256 x 256 pixel resolution, up to 130 full frames per second, temperature resolution greater than or equal to 0.015°C, a snapshot mode, a motorized, five-position filter wheel, and a closed-cycle, sterling linear cooler. These capabilities far exceed other IR cameras currently on the market.

The thermal diffusivity mapping feature works by recording the thermal response of the sample to an external heat source. Heat sources include lasers, xenon flash lamps, quartz lamps, and xenon illuminators. Thermal diffusivity is measured by supplying the heat to the side of the sample which lies opposite to the camera. The sample must be planar. The sensitivity of the IR camera can recognize microstructural changes in the sample.

HTML's IR camera demonstrated its value through a project with the Ford Motor Company. Ford suspected that a micro-material problem existed in its brake rotors. Whenever the brakes were applied, hot spots occurred in the rotors and caused the vehicle to vibrate. Warranted repairs created an expensive cost for the company. HTML investigated the problem by using its IR camera to analyze a brake rotor setup on a brake dynamometer at the Ford laboratory. Within minutes, the IR camera revealed the hot spots and provided valuable data to the automotive engineers for solving this problem. Previously, Ford had tried to investigate the brake problem by using three other IR cameras, but with no success.

Other projects performed with HTML's IR camera include thermal diffusivity mapping of carbon-carbon composites; identification of subsurface flaws in turbine engine coatings; and thermal image of voltage breakdown in a varistor. Future projects include monitoring cyclic, fatigue testing of turbine blades; heat spreading in electronic packaging substrates; thermal shock damage to composites; and process optimization in the pulp and paper industry.

High Temperature Materials Laboratory

As a national-designated user facility, ORNL's High Temperature Materials Laboratory (HTML) provides advanced materials characterization for high temperature materials through its six user centers. Each center houses specialized equipment for a specific property measurement such as materials analysis; thermophysical properties; diffraction; residual stress; machining and inspection research; and mechanical characterization and analysis.

HTML assists industry, university, and government customers through various programs. The User program offers short-term material characterization on either a proprietary or non-proprietary research basis. With non-proprietary research, the customer uses the facilities free-of-charge provided that the results are published. With proprietary research, the customer pays for use of the facility. The Fellowship program, designed for longer-term research including more basic studies, offers industrial, graduate, and faculty fellowships. More than half of HTML's work comes from CRADAs and other branches of DOE.

HTML offers state-of-the-art equipment and highly-trained employees to assist its customers with research. By addressing issues in ceramic machining and inspection; residual stress of thermal barrier coatings; catalyst investigation; advanced ceramic development; stress and reliability analysis of ceramic components; mechanical characteristics of ceramic engine components; and residual stress in brake-rotor design, HTML has assisted industry in solving tomorrow's material and manufacturing problems for high temperature materials.

In operation since 1987, HTML has established over 129 industry and 124 university user agreements which resulted in over 600 projects. Participation includes large and small customers such as Brown University, Penn State, Cummins Engine Company, Allied Signal Engine Company, General Electric, NASA, and LoTEC.

Hydroforming Tool-Die Design Advisory

Oak Ridge's Y-12 Plant uses hydroforming techniques to produce precise, thin-wall part geometries that would otherwise be difficult and expensive to manufacture with standard manufacturing techniques. Although hydroforming equipment can easily be obtained from commercial vendors, the

procedure requires considerable expertise to achieve a low-percentage part and/or tool-die rejection rate and maintain efficiencies, precision, and consistent quality. Many highly-skilled key individuals who obtained this expertise over the years are approaching retirement age. The Hydroforming Tool-Die Design Advisory (HTDA) effort extracts this knowledge and makes it available to less-experienced individuals. In addition, the integration of modern computer techniques into various aspects of hydroforming extends a facility's assets and allows its employees to reach higher skill levels.

Y-12 needed a systematic approach that could collect all-known pertinent data and information, minimize its impact on current hydroforming activities, and be consistent with future computerization and integration (long-term strategic) plans. Over the years, research determined that math modeling would not provide all the answers and only worked best with very specific, well-defined issues. HTDA uses geometry, forming problems, requirements, constraints, guidelines, and any other pertinent information. Based on reduced-order, feature-based modeling instead of traditional finite-element modeling, HTDA can operate within seconds as opposed to several weeks. The system selects the tube size and performs a bending analysis to determine factors such as optimal procedures, machine parameters, and machine setups for making quality parts with low rejection rates.

General Motors implemented HTDA for the production of a typical, water-die hydroformed part used in automotive applications. After bend analysis, the system significantly reduced the number of dies necessary to fabricate the part. In addition, HTDA successfully replicated a reoccurring failure which the 3-D finite element model failed to identify.

By capturing design and process knowledge, HTDA is very effective in determining potential problems which usually would not be discovered until the latter stages of production (after the dies have been fabricated and tested). The system can also be used in production planning, such as concurrent engineering activities or optimal production scheduling, to make quality parts with low rejection rates.

Machine Vision Technologies

ORNL's Image Science and Machine Vision (ISMV) group conducts pure and applied research in the machine vision and perception areas. ISMV's goal is to develop human-level visual and decision-making capabilities for computers and robots by emulating human sensory and cognitive processes. Over the years, the group developed many methodologies and systems for the U.S. industry and federal government to reduce waste and energy usage, and improve manufacturing processes and product quality. One technology developed by ISMV, Spatial Signature Analysis (SSA), is licensed to several suppliers to the semiconductor industry.

Currently, semiconductor manufacturers use image-based, defect detection and review workstations to process the monitoring and characterization steps. This method generates a huge amount of data which must be evaluated by production personnel. Alternatively, SSA works as a data-reduction process by automating the detection and classification of patterns or process signatures. These signatures are based on electronic wafermap data provided by current in-line measurement tools. The SSA process begins with a coordinate list of defect data points which are mapped to pixels in a wafermap image. Next, the images are subsequently organized into shapes, objects, and finally signatures. The signature feature description, embedded in the software, determines the defect classification. After completing the classification, the review for intelligent sub-sampling of off-line high-resolution defects can occur.

Integration of SSA technology with in-line defect detection and analysis strategies will result in product-yield improvements. ISMV estimates the investment return of SSA throughout the semiconductor industry at over $100 million per year for a 0.1% improvement in yields.

Mass Flow Controller

Mass flow controllers (MFCs), one of the most commonly-used components in the semiconductor manufacturing production line, exist in 75% of all process tools. Used to regulate process gas flow, these components must be accurate, reliable, clean, and have reproducible performance parameters. However in 1991, MFCs were identified as the most failure-prone component in the U.S. semiconductor industry.

In 1993, SEMATECH contracted ORNL to develop a facility for evaluating and improving MFCs. The Mass Flow Development Laboratory (MFDL), a state-of-the-art facility, houses three testbeds and uses 15 standardized test methods which were developed by SEMATECH and ORNL personnel.

The three testbeds evaluate the performance of MFCs for reliability, accuracy, and environmental effects. Unique features of the MFDL include:

- Standardized Test Methods establish a uniform comparison for all MFC types and characteristics.
- Gravimetric Calibrator provides high accuracy, high speed (hours versus days), and high safety (no disconnect for hazardous gases) testing. ORNL won the R&D 100 Award in 1995 for the development of this calibrator and holds an international patent.
- Reliability Testing has 28 parallel flow loops and accelerates life cycle tests while maintaining parallel and comparable test configurations.
- Accuracy Testbed provides high-accuracy, high-safety, and fully remediated testing of process gas flow. This automated testbed uses one parallel testing loop and a class-100 clean room environment.
- Hazardous Process Gas Flow Testbed allows for the handling of toxic, corrosive, and flammable process gases.

In 1995, the MFDL became a DOE National User Center which provides industry, university, and government customers easy access to the facility. It is estimated that a 0.01% increase in semiconductor yields could result in a savings of over $100 million per year throughout the U.S. semiconductor industry.

Mass Spectrometer Improvements

Mass spectrometry remains one of the most widely-used analytical techniques. ORNL has maintained a long history in fundamental and applied mass spectrometry since the 1940s. Recognized as a world leader, ORNL continues to improve upon this technology.

Every two to four weeks, gas chromatograph/mass spectrometer (GC/MS) systems are typically calibrated by disassembling and cleaning the system. In addition, many organic compounds are subjected to thermal and catalytic breakdown in conventional GC/MS systems. ORNL designed a double-oven injection system for use with GC/MS systems which reduces the amount of calibrating and cleaning required by the system. The new design also operates the ion source at less than 80°C which prevents thermal and catalytic breakdowns and increases detection limits by 10 to 100-fold. Installed over five years ago, ORNL's system regularly scores 100% on the initial attempt against the EPA's Contract Laboratory Practices, Performance Evaluation Testing, and Proficiency Analytical Testing calibration test samples. In addition, the system can be run for 2,000 to 3,000 hours (six months to a year) without requiring cleaning which decreases non-productive labor and instrument downtime.

To prevent the detection of drugs, illegal drug users devise ways of adulterating their body fluids. ORNL developed mass spectrometers which can defeat these adulterations by analyzing body fluids through a direct sampling method. This method reduces analysis turnaround time from five hours (or more) to less than three minutes. Although ORNL concentrated on the detection of THC-COOH (marijuana) in urine samples, future developments will allow other types of drugs to be detected. In addition, ORNL uses solid phase membrane extraction (SPME) for the direct extraction of organic compounds (contaminants, explosives, drugs, organic solvents) from the air as well as body fluids. SPME, in combination with GC/MS, creates a very powerful and fast analytic technique.

Other technology developed by ORNL include:

- Ion trap mass spectrometers to rapidly analyze water, soil, and airborne contaminants.
- Small and micro mass spectrometers to study exhaust manifold gases from diesel and gasoline engines. Estimated total system cost is less than $5 thousand.
- Air-sampling mass spectrometers with a Townsend Discharge chemical ionization source which is not affected by O_2 and H_2O.
- Sensor mass spectrometers which use low voltage electron impact, instead of an inlet separation device, to directly monitor air.
- Quadrupole and magnetic-sector, mass-analyzer mass spectrometers with ion sources that function in the 10^{-3} Torr region and produce excellent quantitative results between 10^{-8} and 10^{-3} Torr.

Multiple Thin Sheet Production

NASA Marshall Space Flight Center needed thin (0.05 to 0.08-inch) sheets for destructive testing to determine the dynamic fracture performance of space station wall panels. Requirements included manufacturing the sheets from aluminum 2219; withstanding hypervelocity impact of small space debris at speeds up to 11 kilometers per second (24,000 mph); and possessing a fracture toughness which could withstand crack propagation.

Typically, the material for a test sheet was taken from the center inch of a three-inch aluminum slab. To produce a 0.08-inch test sheet, the manufacturer started with a 3 x 48 x 72-inch slab and then removed 1.46 inches from the top and bottom by milling. This technique ensured the elimination of inclusions which usually lie near the surface of materials produced in this manner. However, the cost of material and labor made this method unacceptable. After unsuccessful attempts to locate a better method in industry, NASA approached ORNL.

Starting with a 3 x 48 x 72-inch aluminum slab, ORNL used a horizontal bandsaw (modified to cut metal) to slice six 0.2-inch thick sheets from the center, 1.5-inch section of the slab. Next, a rolling belt sander ground the sheets to the desired thickness. By using a grid technique with a custom-built, hand-held dial indicator, ORNL verified the final thickness of the sheets against NIST standards.

The new procedure realized a significant savings in material and labor costs. Material costs decreased by six fold while labor costs were reduced by at least five fold. As an added benefit, sheets produced by sawing and belt sanding had lower residual stress in the material than those made by machining. Data achieved through strain gauge hole drilling methods (Figures 2-6 and 2-7) confirmed this attribute.

Pollution Solutions Refrigerant Management

To comply with Section 608 of the 1990 Clean Air Act and to protect the ozone layer, Oak Ridge changed its method of handling refrigerants. Oak Ridge formed a company/union partnership to identify the best ideas, solutions, and methods for incorporating a safe, efficient, user-friendly refrigeration program. A key component of this program involved aggressive training of personnel.

After becoming certified as an EPA Testing Facility, Oak Ridge developed a three-day training program called Protecting the Environment with Refrigerant Management. To give participants a hands-on situation, Oak Ridge built two refrigeration-unit simulators out of scrap parts. Topics covered by this training include Section 608 of the Clean Air Act; American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 15 standards; Department of Transportation requirements; good service practices; record keeping; handling of refrigerants; refrigerant recovery and recycling; refrigerant containments; leak check and repair techniques; equipment maintenance and retrofitting; and alternative refrigerants.

Oak Ridge has trained more than 130 of its technicians and support staff, and over 300 participants from other DOE facilities and private businesses across eastern Tennessee. The training program has now been expanded into an in-depth, interactive, four-day class which is being shown across the Nation via satellite.

Project Environmental Measurements System

LMES' Environmental Restoration (ER) program supports multi-site projects by addressing the release (or threatened release) of potential contaminants from geographical regions and assessing the possible risks to people and the environment. To ensure the data is quickly and accurately obtained, LMES developed the Project Environmental Measurements System (PEMS). PEMS integrates environmental measurements data management with the ER process.

Prior to PEMS, ER teams relied on multiple subcontractors to collect and maintain the data associated with a particular ER project such as environmental compliance requirements or annual assessment reports. As a result, data existed across several companies in varying formats and quality which made data collection and evaluation very difficult. PEMS resolved these obstacles by providing a cradle-to-grave data management system along with a common application software and database which was accessible from numerous locations.

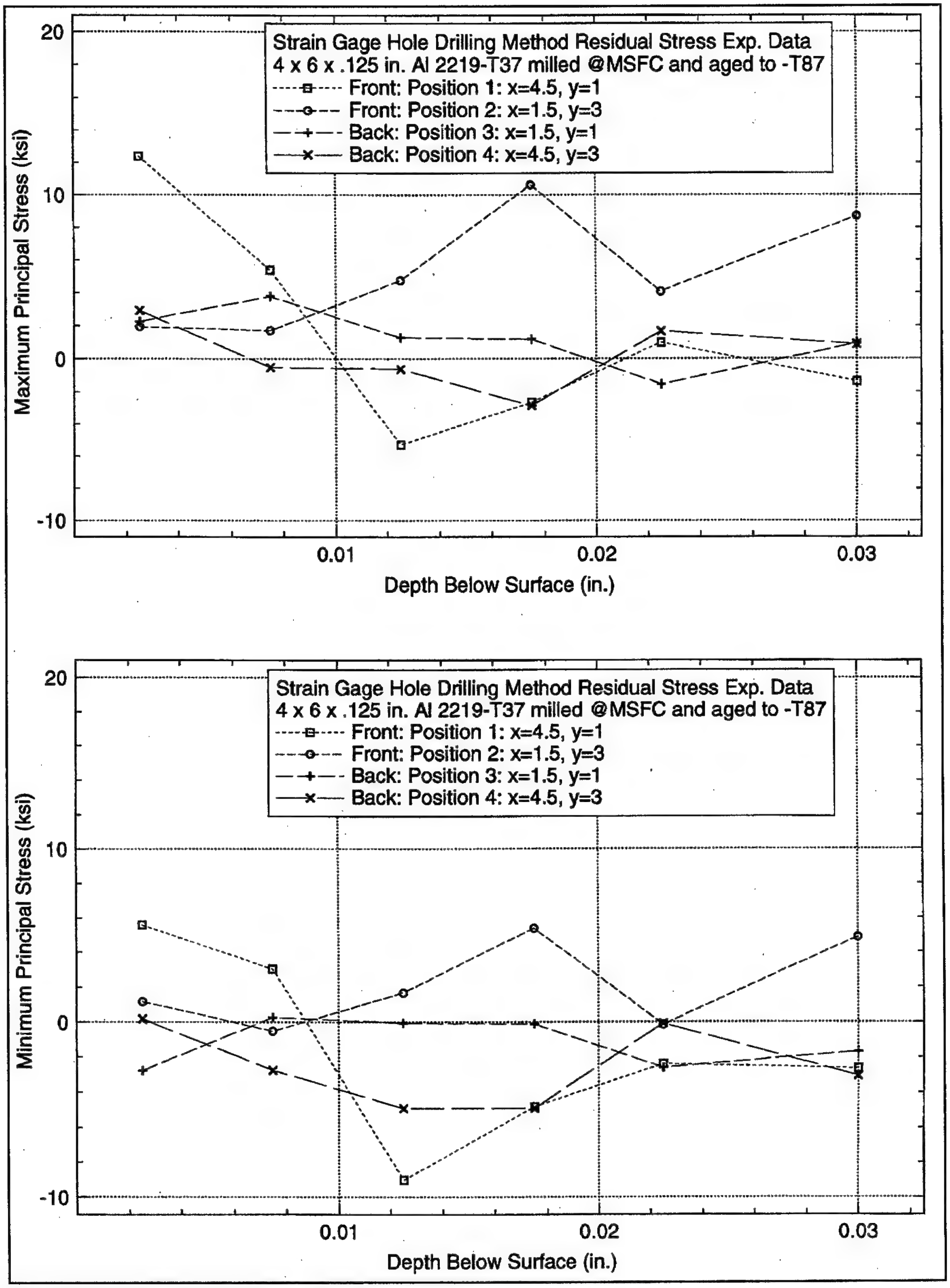


Figure 2-6. Residual Stress After Machining

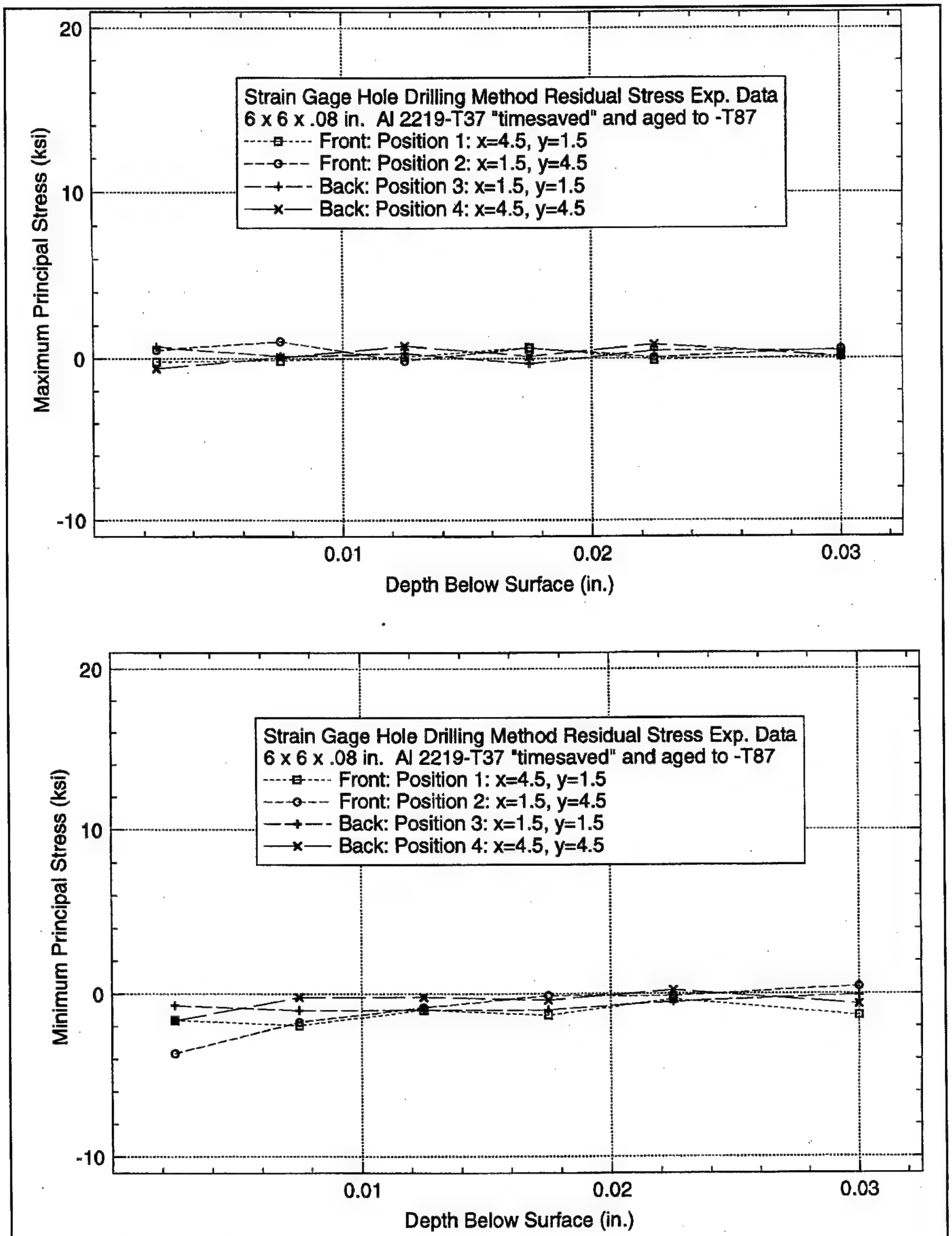


Figure 2-7. Residual Stress After Sawing and Milling

PEMS works with large or small projects, supports various environmental media (groundwater, surface water, air, soil, sediment, biota), and adapts to variations in a project's workflow. The system provides reference tables to populate sampling tasks (including locations, frequencies, analysis, containers, and field measurements) and supports sample planning activities (including the generation of sample container bar code labels). PEMS keeps track of a sample's status and the forms and logbooks associated with sampling events. By collecting information from field sheets and sample containers, PEMS generates Chain of Custody documentation for sample shipment. In addition, the system supports electronic loading and screening of analytical results to ensure quality data.

With success over the past year at three Oak Ridge sites and the Sandia National Laboratory, PEMS is currently being put into operation at DOE facilities in Paducah, Kentucky and Portsmouth, Ohio. As a result of using this system, ER data can be captured and verified as it is created. PEMS omits multiple searches, reduces data maintenance, and eliminates redundant and complex systems. Oak Ridge realized a savings in excess of $500 thousand from these benefits. In addition, PEMS is model driven which allows for adaptability to any environmental project requiring sampling and analysis. After adapting PEMS for use at Sandia National Laboratory, the facility reported a savings of $1 million.

Pulsed Laser Deposition Technology

With its laser expertise and equipment, ORCMT began using pulsed laser deposition (PLD) to develop new thin film materials and associated advanced manufacturing technologies. PLD uses focused high-energy laser beams, pulsed for nanoseconds, to concentrate a tremendous amount of energy on target surfaces. This process ablates the target materials and produces a directed plume of vapor for depositing on substrates. PLD can form thin films of crystalline and amorphous materials at thicknesses up to several microns.

Because of its simplicity, PLD possibly provides one of the least expensive and more efficient methods for growing thin films. In addition, PLD does not require excessively high vacuums like other standard methods and is amenable to standardized formation recipes for many similar materials. ORCMT's current PLD capabilities include the fabrication of high-temperature superconductors, optical switches, thermographic phosphor layers, and enriched boron layers for neutron detectors.

ORCMT has also developed patented techniques for improving the basic PLD system design and performance. These techniques relate to fast switching of laser targets, split beam laser ablation (i.e., Laser Ablation from Rapidly Exchanged Sources [LARES]), and specialized film growth chambers (i.e., Individual Controlled Environment for Pulsed Addition and Crystallization [ICEPAC]) for volatile element condensation and film ordering. In addition, the techniques will be applied to the development and manufacture of new high-quality materials, compounds and components. ORCMT's unique expertise in PLD technology will enable the facility to generate materials which cannot be produced through any other method.

PLD technology has many applications within the defense community. PLD can form high-quality crystalline sensors for guidance systems, layered coatings for flat panel displays, complex optical components for ultra high-speed hybrid networks, and numerous other specialized applications.

Recycling Program

Oak Ridge's Y-12 Plant presented a challenging situation for recycling because of its size (811 acres) and the possibility of radioactive material. In August 1992, the plant initiated the Y-12 Recycles program to investigate, educate, and create awareness about recycling. An investigation revealed that over 50% of the material sent to the landfill by Y-12 was recyclable. In 1993, Y-12 established a baseline and set a 20% reduction goal by 1999.

By 1995, Y-12 achieved a 25% reduction in landfill usage through its recycle program. Each building housed a mini-recycling center which focused on mixed paper, file folders, aluminum cans, toner cartridges, and corrugated cardboard for recycling. Although most of the collected material can be sold, aluminum and wood require special handling. Y-12 donated 98% of all the aluminum cans (approximately $41 thousand) to 205 local charities. In addition, the plant purchased a large tub grinder to allow the groundskeepers to mulch the collected wood.

The recycle program also features the Swap Shop which keeps an inventory list on excess furniture, tools, electrical equipment, computer

hardware/software, and chemicals. Departments throughout Y-12 can avoid procurement costs by shopping from the Swap Shop. In 1995, Y-12 participated in 442 swaps with over $937 thousand in avoided procurement costs. Many other methods reflect Y-12's commitment to recycling. The employees at the Y-12 garage created additional savings by establishing a loop program for replacement parts which ensures that all replaced cores are returned to the suppliers. The 13,000 tons of fly ash generated by the Steam Plant each year is now used by a local cement manufacturing facility.

Because of the effort and dedication of its employees, Y-12's recycling programs proved to be effective in minimizing waste. In 1996, the Plant was recognized for its recycling programs and received the Department of Energy's Environmental Award.

Superplastic Forming Technology

Since the early 1980s, Oak Ridge's Y-12 Plant has been developing thermomechanical processing parameters and superplastic forming techniques for hundreds of parts. Superplastic forming came about because of the expense associated with processing and forming uranium alloys. By utilizing computers and process optimization techniques, superplastic forming diminished manufacturing space requirements, decreased material requirements by two-thirds, and significantly reduced processing and forming costs.

Through Y-12's research, superplastic forming can be applied to other alloys besides uranium such as titanium-aluminum-vanadium (Ti-6Al-4V), tin-lead (Sn-Pb), aluminum-magnesium (Al-Mg), and iron-chromium-nickel (Fe-Cr-Ni). Materials that exhibit superplastic behavior are preprocessed polycrystalline solids which can withstand large deformation before failure. Y-12 developed the superplastic forming technique as a sheet forming process where the sheet is placed over a female die and inert gas is applied at a few hundred pounds per square inch maximum.

ORCMT offers superplastic forming facilities for development activities as well as production operations. Capabilities include metallurgical support, dimensional analysis, and computer modeling. The computer modeling capability, based on a commercial package called NIKE, has been enhanced to address specific superplastic forming needs.

Because the superplastic forming process occurs just above the midpoint of the absolute melting temperature of the material, the technique produces a near-net shape, uniformly thick, and relatively stress-free product. The process also uses inexpensive die materials; forms large parts with low pressures; reduces tooling costs and fabrication time; and is inherently safer than the typical punch and die stamping operation.

Technologies Enabling Agile Manufacturing

DOE's Technologies Enabling Agile Manufacturing (TEAM) program seeks to enhance U.S. global competitiveness by advancing and improving the national manufacturing infrastructure. As a technology transfer initiative, TEAM leverages common visions and cooperative alliances among government, industry, and academia to provide practical tools which streamline product development, reduce cost, shorten time-to-market, and enhance quality through integrated design-to-manufacturing solutions. Guided by a strategic plan, the existing program represents two years' progress into the execution of that plan. TEAM consists of a set of models which define the product realization enterprise, and a growing set of tools which demonstrate and validate the models.

More than 50 government, industry, and academic partners comprise TEAM and provide in-kind contributions of about $15 million per year. Guided by an industry-led steering board with multi-agency participation, TEAM uses joint industry and government thrust-area groups to provide critical enabling technologies, validate technologies through product vehicle demonstrations, and optimize manufacturing through total system performance.

TEAM's key capabilities include feature-based design and manufacturing tools; a hierarchical modeling and simulation environment; expert tools for manufacturing information creation and management; web-based integration managers; and application programming interface specifications for open architecture controllers. By mid-1997, TEAM hopes to establish product vehicle demonstrations including a GM engine head for integrated material removal, an exhaust nozzle for a Pratt and Whitney jet, and a power supply for DOE weapons mission. TEAM tools are also being implemented by DOE weapons program to produce weapon parts and assemblies.

TEAM possesses several unique characteristics. The program not only addresses manufacturing as

a system, it also measures the value of its tools and technologies to that system. TEAM's tools and technologies can either be used as a modular, standalone feature or as part of an integrated system. In addition, TEAM's open agenda, strategic plan, and cooperative alliance method of operation have resulted in new benchmarks for teaming and cooperation. Because of its success in executing a process, from needs assessments through delivery of solutions, TEAM is providing leadership in the Next Generation Manufacturing (NGM) project. The NGM project is an industry-led effort, made possible with support from DOE, DOD, NIST, and the National Science Foundation. The project builds on other national initiatives to develop a broadly accepted model of future manufacturing enterprises, and to recommend actions that manufacturers (working individually and in partnership with government, industry and academia) can use to attain world-class status.

Ultraprecision Manufacturing Technology Center

As new technologies yield smaller systems, the demand for machining capabilities with submicron tolerances has increased. These machining capabilities, typically used by the optics industry, allow for mirror finishes in the production of microsensors. The Ultraprecision Manufacturing Technology Center provides fabrication methods and precision metrology with submicron tolerances for the U.S. government and private industry. The Center also specializes in single-point diamond turning; ion milling; ductile grinding; and miniature/micro optical systems.

Mounted on a Rank Pneumo Nanoform 600 machine, the Center's single-point diamond turning capability can use either natural or synthetic diamond tools. This capability enables the user to fabricate complex surface finishes such as those used in telescope lenses.

Ion milling, the Center's most accurate machining capability, can remove material at the atomic level. By using argon ions, a concentrated beam strikes the workpiece and physically dislodges the atoms located at the surface. The user controls the amount of material removed by regulating the exposure time of the workpiece to the argon beam.

The Center's ductile grinding capability uses a Precitech Optimum 2800 machine with an air-bearing spindle and diamond grinding wheel. Typically, this capability is performed on an ultraprecision ceramic substrate such as silicon carbide or sapphire.

The Center's miniature/micro optical systems, such as its monolithic minispectrometer, demonstrate that high-performance instruments can be built in small sizes and at low cost. These instruments have applications in environmental monitoring, on-line process monitoring, remote sensing, and chemical detection.

Through technology transfer, the Ultraprecision Manufacturing Technology Center's capabilities are available to government and industrial customers. Typical activities include problem solving, researching, and prototyping. Currently, the Center is working with the U.S. Navy on improving the safety of microsensors used in torpedoes.

Virtual Training Simulator

Developed by ORCMT's Concurrent Engineering Center, the Virtual Training Simulator provides computer simulations for operating industrial equipment such as milling machines and other highly complex tools. The student views a 3-D, color simulation of the equipment on a computer monitor and operates the equipment with a controller. The controller, consisting of a control panel and data viewing screens (Figure 2-8), allows the student to run all aspects of the simulated equipment. In addition, the student can simultaneously view the controller and the simulated equipment in operation.

The Virtual Training Simulator provides the student with a realistic training environment, hands-on operating experience, and real-time feedback. Since the simulator runs at higher speeds than the actual equipment, training time is reduced. In addition, the student has the option of immersing into a virtual reality environment by using a virtual reality helmet and hand-held control unit (Figure 2-9). The simulator allows for multiple collaboration and workstations. A single student can work on multiple pieces of simulated equipment, or several students can simultaneously operate the same piece of simulated equipment. Training sessions can also be conducted from remote sites.

The simulator eliminates the need to buy equipment exclusively for training, which reduces procurement costs; prevents the need to remove equipment from the production line for training, which

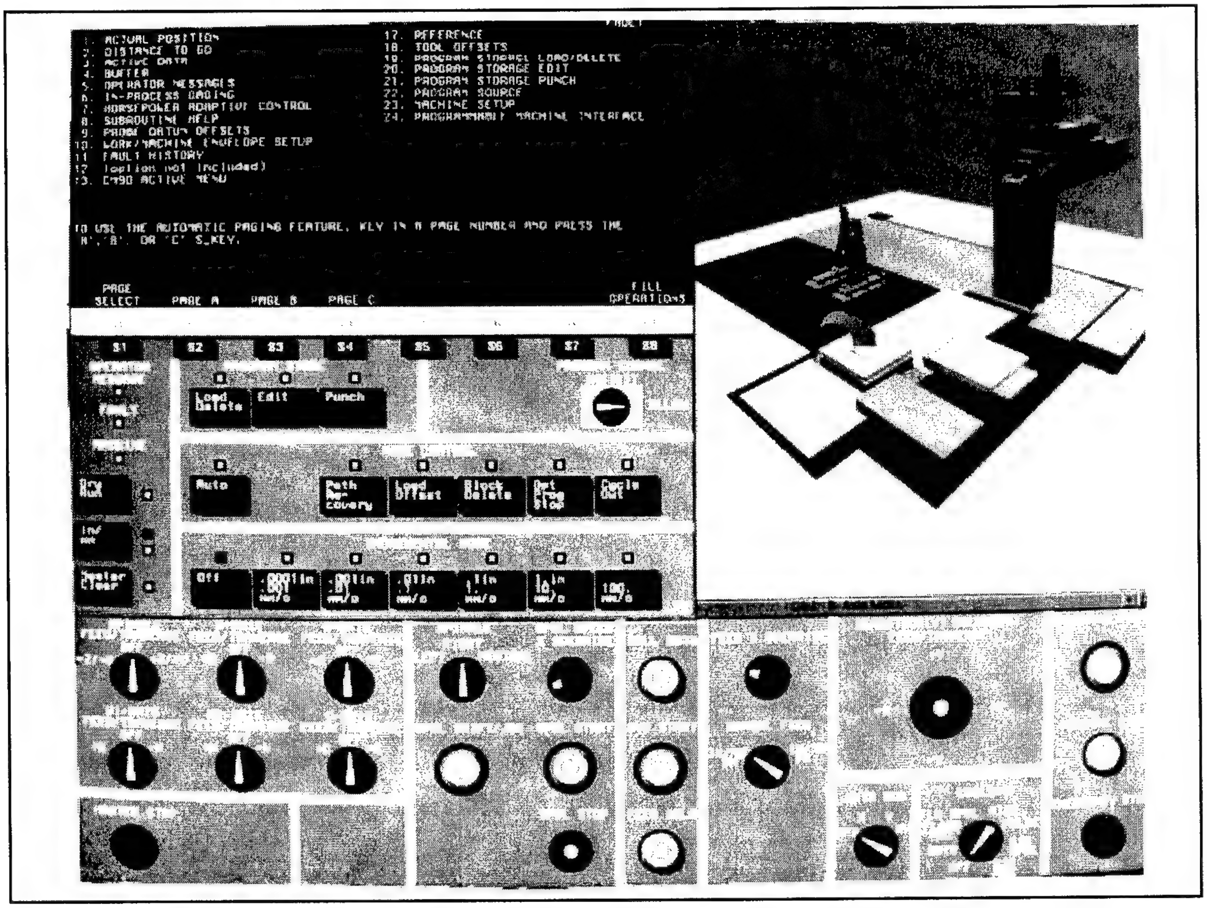


Figure 2-8. Control Panel Simulation

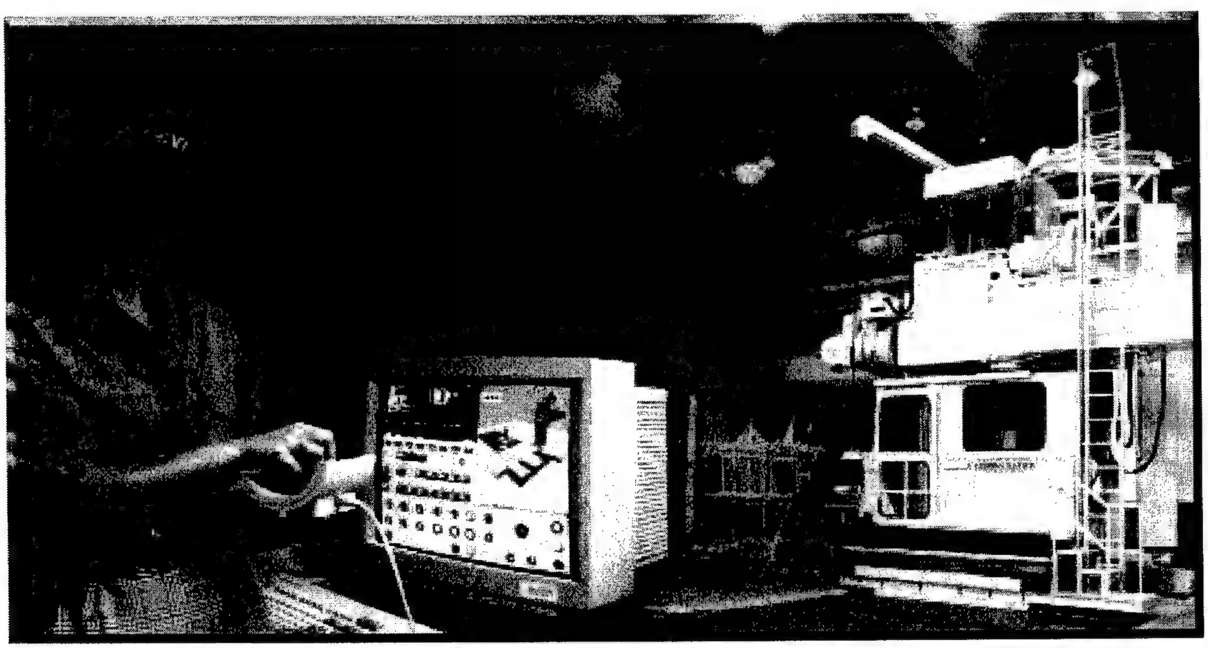


Figure 2-9. Realistic Computer Training Simulators

reduces down time; and protects expensive equipment from damage by inexperienced operators during training, which reduces repair costs. In addition, 3-D, close-up views of the simulated equipment in operation enable the student to detect potential collisions and damage quicker than if the actual equipment were used.

ORCMT's Virtual Training Simulator can be run on a personal computer. The models used by the simulator were created from commercially-available software. A toolkit for creating controllers of simulated equipment is available, along with ORCMT's archive of simulated machines and controllers.

Waste Information Tracking System

The Oak Ridge facilities generate a diversity of waste materials including sanitary, spent nuclear fuel, low-level, mixed, RCRA, and transuranic/transuranic mixed aqueous solutions. These materials must be tracked and managed in accordance with federal and local regulatory requirements. In addition, all transportation and handling of the materials must be recorded, including repackaging, shipment, and disposal. The Waste Information Tracking System (WITS), developed to handle the large quantity of data, currently operates at the Oak Ridge Y-12 Plant, the East Tennessee Technology Park, and ORNL.

The computerized WITS works as a model-driven, production-quantity application and tracks all types of waste materials. The system coordinates data on project information; requests for disposal; sampling and analysis; waste characterization; transportation; shipments; repackaging; and reporting. WITS provides consistency for business practices across waste management and restoration functions; eliminates redundancy of tracking systems; and produces quality data. Implementation of WITS has also led to more consistent and accurate reports to regulatory authorities.

As a highly-adaptable, user-friendly system, WITS can perform in various hardware and software environments, and provide reporting functions and query options through Microsoft Access. In operation at the three facilities for five years, Oak Ridge estimates a savings of $2 million in waste tracking costs.

Facilities

Analytical Development Department

LMES' Analytical Services Organization (ASO), a full service organization, is supported by more than 370 chemists, technicians, engineers, and supporting crafts. ASO has won DOE's Quality Award for three consecutive years and the State of Tennessee's Quality Award for two consecutive years. The Analytical Development Department (ADD), a section of ASO, provides practical solutions to industrial problems through innovation and state-of-the-art technology.

ADD's strength lies in its flexibility to form technical assistance teams who focus their expertise on finding solutions to complex chemical problems. Within the last 20 years, ADD's expertise has solved nonroutine chemical problems involving polymers, gas mixtures, complex organic compounds, exotic metal alloys, radioactive materials, and hazardous materials for a wide variety of matrices and on-line monitoring instrumentation. Analytical instruments available at ADD include mass spectrometers (organic, glow-discharge, and gas); molecular spectroscopy (Fourier transform infrared, nuclear magnetic resonance, Raman, gas chromatographs, and x-ray diffractometer); and surface method instrumentation (multiprobe, microprobe, scanning electron microscope, and ion chromatograph).

Through a cooperative network, ADD can also access assistance from ORNL and the University of Tennessee. With its networking, expertise, and state-of-the-art technology, ADD can provide its customers with all aspects of its analytical services.

Electrical Signature Analysis

Most industries rely on electric motor and generator operations. However, corrective and preventative maintenance practices are more costly solutions than condition-based servicing of rotating equipment. Motor total current analysis is typically limited by gross variations of loads, and vibration analysis can be a time-consuming task. To better predict motor and rotating machinery performance degradation at a decreased cost, ORNL developed and patented several electrical signature analysis (ESA) techniques.

Traditional methods of analyzing load and performance with total current and power monitoring cannot provide the high resolution needed to describe evolving faults or small variations in the applied loading. The alternative is the more-costly, less-effective mechanical vibration analysis which uses multiple sensors. However, the increased cost and complications associated with monitoring prevent operators from detecting problems with the motors or generators located inside their manufacturing plants.

ORNL required proven methods to monitor and control its weapons and nuclear operations. With that initial goal, ORNL developed several signal conditioning and signature analysis methods that exploit the intrinsic abilities of conventional electric motors and generators to act as transducers. By using simple COTS current and voltage probes (Figure 2-10), ESA detects and analyzes the small time-dependent load and speed variations generated within an electro-mechanical system and converts them to frequency signatures which are useful for both mechanical and electrical fault detection. ESA provides similar data from its one non-intrusive probe (current analysis for motors or voltage analysis for generators) as conventional vibration analysis does with its multiple sensors.

ORNL demonstrated the motor (current) analysis of the ESA method on an Army program which monitors a motor-conveyor system on an ammunition resupply vehicle. Similarly, ORCMT successfully completed generator (voltage) analysis for a test-stand demonstration on the internal drive generators of 757 and 767 aircraft engines. Furthermore, a prototype ESA is monitoring the 19 motors which drive the chilled water pumps at ORCMT and tracking the pump performance via current variation.

Applicable to any motor-load or prime mover-generator system, ESA methods work as a maintenance aid and method for tracking overall performance. ORCMT used ESA to track actual load requirements of a 350 hp, 1800 rpm motor. After reviewing the data, ORCMT decided to replace the motor with a smaller, 125 hp, 1200 rpm motor and realized an annual operating cost savings of $50 thousand. ESA's most attractive benefit is its cost savings associated with condition-based maintenance in manufacturing and operational environments. ORCMT documented a 1989 study on the costs associated with various maintenance strategies used on rotating equipment. The study esti-

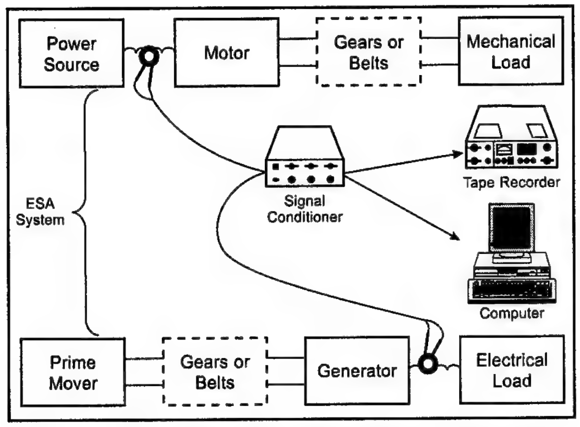


Figure 2-10. Electrical Signature Analysis

mated the normalized cost per year at $18 per hp for corrective, $13 per hp for preventative, and $10 per hp for condition-based maintenance.

High Performance, Direct-Drive Motor

ORCMT established a CRADA with Quick-Rotan, Inc., the only remaining U.S. manufacturer of sewing machine motors, to develop a small, high-efficient, direct-drive motor which could be mounted on the top of commercial sewing machines. This new motor would revolutionize the apparel industry by eliminating the large, belt-driven AC servo-motors which were mounted underneath the sewing machine.

Various obstacles were faced during the development of the new motor. To meet required specifications, ORCMT and Quick-Rotan modified an existing motor which allowed it to be integrated onto a sewing machine shaft. Next, they designed a control system which enabled the motor to stop at the needle-up position and accurately step up and down from 10,000 rpm.

The completed CRADA project produced a 1.4 hp, permanent-magnet, DC motor (approximately the size of a soda can) which can successfully drive a commercial sewing machine at speeds up to 10,000 rpm. Top speeds of previous sewing machine motors ran at 5,000 rpm. Advantages of this top-mounted, direct-drive motor include easier swapping of motor heads, less maintenance (no belts or pulleys), less heat, and more operator leg room. A direct-drive DC motor can deliver more torque with less power loss from friction or gearing, allowing a 1:1 ratio of rpm to stitches per minute to be achieved; previous motors had a lower

ratio. Demonstrated at the 1994 Bobbin Show, the new motor received rave reviews and easily exceeded other motors developed by overseas competitors. The apparel industry has long sought this innovation which will lead to more cost-effective production and faster maintenance.

Paperless Office

The Advanced Neutron Source (ANS) project, a proposed $2.9 billion research facility, would have furnished steady-state beams of neutrons for experiments conducted by more than 1,000 researchers per year. The ANS facility would have provided research in the fields of material science, engineering, biology, chemistry, materials analysis, and nuclear science, including irradiation capabilities to produce radioisotopes for medical applications, research, industry, and materials testing.

The ANS project has produced a paperless office infrastructure to handle all information electronically. It was estimated that more than 100 million pages of paper would be generated and managed over the proposed 10-year design of the ANS project. Storing that much information on paper would require the construction of a new building as well as additional personnel for handling the massive amount of paper.

Developed by LMES' Information Management Services and Central Engineering Services, the paperless office infrastructure consisted of a Banyan VINES local area network which is now being migrated to an NT server. During the proposed 10-year life of the ANS project, the infrastructure was estimated to produce a cost savings of over $60 million.

Upon cancellation of the ANS project, all project information including text; photos; engineering drawings; 3-D images; research and development codes for neutronics; videos; and thermal hydraulics were stored on two CD-ROMs. These CD-ROMs permit full interaction with the user through self-extracting, multiple, software applications. In addition, the CD-ROMs cost only $7 per set to produce versus the $35 thousand cost needed to gather the material in paper and ship it to a requester. This impressive use of technology should be considered the benchmark for all future, large-design projects.

Training Activities

ORCMT realized a major problem was developing in early 1993. Although downsizing reduced the workforce, the remaining employees lacked the cross-training in skills of those eliminated. This realization became especially obvious when attempts to hire new employees with these skills proved difficult, if not impossible. ORCMT held meetings with unions, technical personnel, and management to determine a strategy for the future. The result produced a new method for performing work on-site at ORCMT and providing assistance to off-site educational institutes.

Meetings with schools and community groups provided a way to incorporate the teaching of students and instructors into the production skills sought by ORCMT. The Mobile Manufacturing Learning Center, a trailer outfitted with everything necessary to make a production part, traveled throughout Tennessee to enlighten young students about the manufacturing field. ORCMT established career days with local schools and provided vocational students with an opportunity to visit its facility and learn how to use tools, such as lasers, grinders, coordinate measuring machines, and milling machines.

Training activities were established at ORCMT. Employees began receiving cross-training courses, on company time, so their technical expertise could be broadened. In addition, the first of the train-the-trainer classes was completed in early 1994 and proved to be very effective and successful. Craftworkers became proactive and were very instrumental with the marketing of the business development initiatives.

Presently, the training activities established by ORCMT have broadened the skills of its employees, initiated referrals from skilled craftsman for engineering training, provided simulator models for training classes, and generated a skills campus trainers survey in Chattanooga, Tennessee. In addition, the Mobile Manufacturing Learning Center educates young students throughout the state on the importance of manufacturing skills and provides a free opportunity for them to acquire some craft skills.

Ultrasonic Cleaning

Over the past 13 years, the Oak Ridge Y-12 Plant investigated and developed environmentally-safe replacements for chlorinated solvents (degreasers and cleaners) and strippers (paint and adhesive). By using analytical instruments to study materials and contaminants, researchers determined the baseline cleanliness levels needed for specific applications.

Y-12 has been able to change most of its cleaning operations from chlorinated solvents to aqueous cleaners. The most common aqueous cleaning methods include agitated, high pressure spray, and ultrasonic. Agitated, an immersion cleaning technique, works well for gross contamination removal. High pressure spray also works well for gross contamination removal and is frequently used for lines with high production rates. Ultrasonic, another immersion cleaning technique, determines its effectiveness by cavitational intensity factors. Most industrial users who have switched to aqueous cleaners rely on the agitated or high pressure spray methods. Y-12, instead, pursued ultrasonic methods which use aqueous cleaning solvents.

Y-12's research indicated that critical cavitational intensity factors influence the effectiveness of ultrasonic cleaning. These factors include the ultrasonic frequency; the surfactant type; bath temperature; and coupling between the cleaning equipment and the surfactant. Variations in these factors will determine the degree of cleanliness for the material being cleaned.

Y-12's ultrasonic cleaning demonstrations have brought about technology transfer with the U.S. Army and a CRADA project with an automotive company. In addition, Y-12 provides direct assistance on ultrasonic cleaning to over 30 businesses in the electronics, medical, and metal fabrication industries.

Valve Monitoring

In 1985, ORNL began a comprehensive aging assessment of motor operated valves (MOVs) at the request of the Nuclear Regulatory Commission who was concerned about the aging infrastructure of nuclear power plants across the country. ORNL focused on identifying ways to monitor the service wear of MOVs so that maintenance could be performed prior to failure. In addition, the study investigated methods for collecting data from a motor's running current which could be acquired remotely and nonintrusively.

The ORNL study yielded two major diagnostic techniques: motor current signature analysis and electromagnetic valve monitoring. Research on MOV motor current led to the development of several signal conditioning and signature analysis methods, known as motor current signature analysis, which exploit the intrinsic ability of an electric motor to act as a transducer. Motor current signature analysis detects small, time-dependent load and speed variations generated within a MOV. The variations are then converted into revealing signatures which can identify degradation and incipient failures. This technique has led Oak Ridge's capabilities in electrical signature analysis which is currently being expanded into other applications.

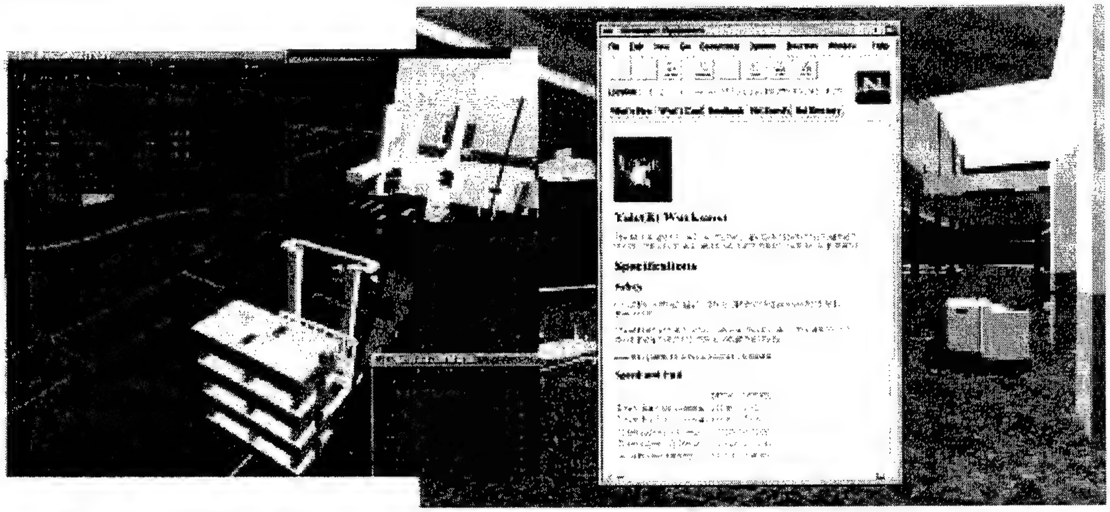
Electromagnetic valve monitoring can detect the operating position of check valves through nonintrusive means. By placing electrical transmitter and receiver coils on the inlet and outlet side of a check valve, this technique can determine if the value is open, closed, or in a fluttering condition. Remote signal analysis can then verify the operating position of the valve. This technique would be extremely useful in situations where a failed check valve could create explosive fuel or hazardous chemical spills.

On-line monitoring of MOVs, fans, and other rotating equipment has proven to be a cost-effective maintenance procedure for industrial and governmental operations. In addition, these systems could possibly provide data for decision-making processes on equipment replacement and operating costs.

Virtual Factory

ORCMT's Concurrent Engineering Center developed a virtual factory software package which uses COTS software tools to design factory layouts, manage factory efficiencies, and develop ergonomic work atmospheres. Its point-and-click feature (Figure 2-11) provides the user with relevant drawings, procedures, images, simulations, and factory information. This state-of-the-art technology can be used in any factory setting and would be a valuable tool for production environments.

The Concurrent Engineering Center modified the commercially-available software QUEST/IGRIP into a 3-D modeling tool which simulates a discrete and continuous factory process (Figure 2-12). Not only does this tool provide a virtual factory's layout and operation, its also records the production time cycles so the user can reconfigure layouts and personnel interactions. Equipment specifications such as dimensions, speeds, and potential are integrated into the software package and can be obtained via Netscape linking. With this feature, the user can predict production cycle times or access specific information from captured process and equipment statistics. Human software models are also implemented to provide ergonomic move-



- 3D Visualization of Factory Layout
- Discrete and Continuous Factory Process Simulations *(What-If Scenarios)*
- Point-and-click access to drawings, procedures, databases *(Training)*
- Access to manufacturing applications and legacy information *(Knowledge Capture)*
- Capture of process and equipment statistics *(On-Line Information Archive)*

Figure 2-11. Definition of Virtual Factory

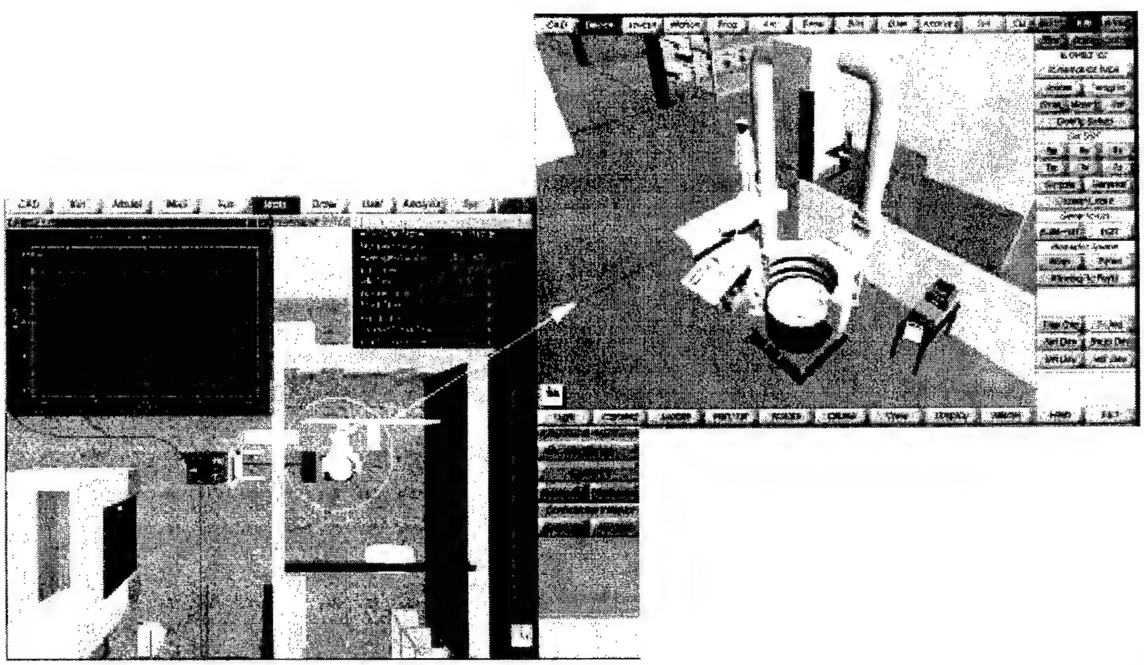


Figure 2-12. Software Tool Integration

ments and reduce repetition stress which typically occur in a factory environment.

The virtual factory tool reduces costs associated with building new factories by providing an efficient method for determining an optimal design. In addition, the software could reevaluate, expand, or redesign an existing factory layout for new product lines.

Management

Knowledge Preservation Program

In 1993, the Defense Nuclear Facility Safety Board (DNFSB) made a formal recommendation to DOE to mitigate the loss of safe operations knowledge at the Nuclear Weapons Complex sites. The targeted sites were the weapons testing in Nevada and the weapons dismantling at Pantex in Texas and the Oak Ridge Y-12 Plant in Tennessee. DNFSB's recommendation came about from the downsizing activity at the time and the projected continuation of downsizing for the future.

Each targeted site worked directly with DOE to develop its own Knowledge Preservation program on safety, assembly, processing, disassembly, and quality evaluation. Program objectives were to promote safe nuclear operations and preserve anecdotal operations knowledge for future workers. Program benefits included preserving safe operation knowledge in an accessible form; providing historical process knowledge for diagnostic and upgrading purposes; and retaining knowledge of existing records for future reference.

Y-12's Knowledge Preservation program, now in its third year, established a highly-publicized electronic archive that contains transcribed interviews from current and retired employees. The interviews can be searched using full text. To date, 187 interviews have been recorded with a potential of 250 total. An interview consists of a one-to-two-hour meeting with an interviewer who guides the open discussion via a questionnaire. The interviews provide a living list of key safety documents and knowledge from employees.

Y-12's initiative to establish an organizational infrastructure strengthened its Knowledge Preservation Program. In addition, Y-12 has demonstrated its enthusiasm, identified its line-organization responsibilities, and received support from its management which will enable the successful continuation of this program.

Manufacturing Means JOBS Initiative

Manufacturing, one of the key drivers of Tennessee's economy, represents 22% of the total jobs in the state. Figure 2-13 shows the impact of manufacturing on Tennessee's economy. To continue its overall economic strategy, Tennessee needs to grow and maintain a strong manufacturing job base through good, high-paying jobs. In response, ORCMT established the Manufacturing Means JOBS Initiative which pulls together the resources and advance economic development within the state. The program combines the cooperative efforts between the Tennessee Department of Economic and Community Development, the University of Tennessee System, the state's Board of Regents institutions, and ORCMT. Through the Manufacturing Means JOBS Initiative, ORCMT envisions Tennessee, by the year 2001, as the number one state in the Nation in percentage of manufacturing job growth.

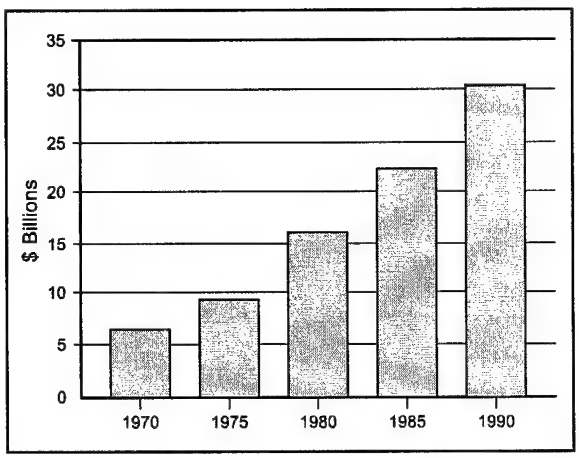


Figure 2-13. Economic Impact of Manufacturing in Tennessee

By integrating all the industrial-extension resources and using economic-development action teams, the Manufacturing Means JOBS Initiative draws together and unifies Tennessee's existing resources. This strategy allows the program to focus on the economic regions and statewide industrial clusters. Objectives include establishing a five-year plan, benchmarking job growth in other states, and demonstrating results by using existing resources. The idea relies on effective networking to enhance what currently exists. Key areas include exporting assistance, supplier develop-

ment, regional initiatives, targeted industrial recruitment, and workforce training. In addition, technology centers, small business development centers, universities, and other manufacturing organizations throughout Tennessee support the Manufacturing Means JOBS Initiative.

Manufacturing Opportunities through Science and Technology

In 1994, the Oak Ridge Institute for Science and Education developed the Manufacturing Opportunities through Science and Technology (MOST) program. Sponsored by ORCMT, the program provides high school teachers with the opportunity to acquire manufacturing knowledge and incorporate this information into their lesson plans.

The MOST program's goal is to increase and improve manufacturing education. Conducted over a four-week summer period at ORCMT, the program focuses on how to transfer manufacturing knowledge to the school system and classroom setting by preparing a well-structured, academic-year plan. More than fifty teachers from various manufacturing education areas such as science, mathematics, and technology have participated in the training program. The Manufacturing Skills Campus provided teachers with hands-on, practical manufacturing demonstrations in product design, product planning, product fabrication, product certification, and process evaluation. In addition, the MOST program presented guided tours through several manufacturing facilities, including the Saturn Plant in Spring Hill, Tennessee. Here, the teachers observed manufacturing and operational skills in a working environment.

Since its start, the MOST program has introduced new programs, modified existing programs, and incorporated new materials into the classrooms. In addition, the program has produced educator teams with enhanced levels of manufacturing skills, educators who serve as representatives for education reform, and changes in the way educators and students view the mixing of vocational and academic skills.

The measured results of the MOST program mirror its accomplishments. Results of the program include the successful introduction and strengthening of curriculum-related manufacturing; the improved appreciation, understanding, and value of vocational and academic programs; and the rise in manufacturing-career choices by students.

Manufacturing Skills Campus

The Manufacturing Skills Campus operates as the training arm of ORCMT. Drawing upon its rich resource of craft skills and knowledge, the Skills Campus provides intense hands-on and performance-based manufacturing training courses for government, industry, and academia.

Craft skills training, an important and powerful tool, has contributed to the successful manufacturing operations at Oak Ridge since the 1960s. Specialized skills and knowledge have helped employees develop and maintain Oak Ridge's highly-technical and unique manufacturing equipment, facilities, and techniques. By the late 1980s and early 1990s, however, changing workloads and job markets created new requirements for the manufacturing field. These requirements included increasing the number of skilled employees in manufacturing, providing cross-training for employees, and furnishing additional training for transitioned employees.

In 1993, ORCMT set up the Manufacturing Skills Campus to address the changing workloads and new requirements. First, internal and external surveys identified the manufacturing training needs of government and industry employees. Based on these results, training courses and experienced instructors were developed. The training incorporates the knowledge and experience gained through decades of experience on numerous precision manufacturing projects performed at the Oak Ridge Y-12 Plant. Drawing upon Y-12's core competencies, the training courses offer advanced hands-on precision machining, manufacturing techniques, materials technology, metrology, quality assurance, energy conscious manufacturing, and environmentally conscious manufacturing to its students. Each course, structured in a modular format, can be tailored to match the needs of the customer. The Manufacturing Skills Campus has partnered with government, industry, and academia through its Mobile Manufacturing Learning Center for high school students, Manufacturing Awareness Academies for teachers and students, and Train-the-Trainer program for instructors. The Skills Campus also delivers national broadcasts on industry-relevant topics via remote broadcasts, and a virtual training model which eliminates traditional cost and schedule barriers.

Unlike most educational institutions, the Manufacturing Skills Campus recognizes and addresses the educational gaps that are unique to the manu-

facturing community. These gaps exist in classroom and on-the-job training (e.g., most educational institutions typically do not offer training in the use of manufacturing equipment). To date, more than 4,500 students from government, industry, and academia have participated in ORCMT's training programs. Students have rated the overall quality of the training programs and its instructors as a 5.0 on a scale of 1.0 to 5.0.

Measurement and Data Management and Analysis

ORCMT calculates its economic impact on customers and improves its operations through a framework of measurement, information, data, and analysis. ORCMT's management and analysis processes are based upon a number of practices developed through benchmarking, experience, and continuous improvement methods. Customer data falls into three categories: internal efficiency, customer satisfaction, and private-sector benefits. Internal efficiency measures ORCMT's effectiveness at providing service in a timely manner and at a reasonable cost. Customer satisfaction measures how satisfied the customers are with ORCMT's services. Private-sector benefits measure the impact which ORCMT's services have on the private sector.

In early 1993, ORCMT began its efforts to measure results. However, benchmarking revealed that many areas had no standardized format to report data. To resolve this situation, ORCMT developed a simple, user-friendly survey for collecting data and a flexible computer software program for sorting and reporting the information. In addition to the data, success stories are maintained in an electronic database which employees can access through ORCMT's internal website.

All of ORCMT's customers are given an opportunity to complete a survey by either telephone, facsimile, or mail; nearly 60% choose mail. Although surveys are tailored to a project, standard questions appear on all versions so results may be aggregated. For private-sector impacts, ORCMT inquires about jobs created, jobs retained, cost avoidance, sales losses avoided, reduced production costs, and increased sales.

Since 1993, ORCMT has realized more than $500 million in private-sector benefits in terms of jobs created and economic benefits. Documentation shows 1,597 jobs have been created; 3,325 jobs have been retained; $78.3 million in cost avoidance; $62.8 million in reduced production costs; $117.2 million in increased sales; $132.5 million in avoidance of sales losses; and $171.6 million in other savings. In addition, data from internal efficiency and customer satisfaction show 75% of customers consider the information provided by ORCMT as useful; 82% of customers rate the overall service quality of ORCMT as good to excellent; and 84% of customers would use ORCMT's services again and recommend it to others.

Mobile Manufacturing Learning Center

ORCMT, in collaboration with the Tennessee Department of Education, established the Mobile Manufacturing Learning Center. This unique learning center consists of a large, mobile trailer equipped with state-of-the-art manufacturing equipment that visits local high schools across Tennessee. Since 1993, the Mobile Manufacturing Learning Center has provided a hands-on learning center and manufacturing demonstration site to more than 9,000 students.

The Mobile Manufacturing Learning Center features state-of-the-art equipment including computers, small robotics, a numerically-controlled milling machine, and a soon-to-be-used video data link. Students can design a part on a computer, send the design to the milling machine, and produce a finished product. The Center exposes vocational students to career options in industry by helping them link their classroom studies (math, physics, drafting, etc.) with potential work tasks. As a result, many students have acquired jobs which were previously unobtainable or unsought.

Student mentors provide much of the training with minimal teacher supervision. The training features team building and team participation, as well as individual experience. As a result, students who have used the resources available at the Mobile Manufacturing Learning Center are now more motivated in their classroom studies. This learning opportunity benefits students and instructors by providing a practical application for standard classroom subjects, hands-on manufacturing experience, and career interest in the manufacturing field.

The mobile learning center concept is available to any state that wishes to combine the theory of classroom studies with the tangible setting of a manufacturing workplace. The total cost, including the trailer and equipment, is less than $100 thousand.

Oak Ridge Centers for Manufacturing Technology Concept

The end of the Cold War shifted the DOE Oak Ridge facilities' focus from producing weapons to enhancing the Nation's industrial competitiveness through the utilization of defense technologies. In addition, Oak Ridge needed a way to maintain its core capabilities (critical to National defense) amidst declining DOE budgets. In response to its changing role and mission, Oak Ridge established ORCMT in 1993. The ORCMT concept is a successful strategy for leveraging and transitioning a major facility from an older mission to a dual-use environment. As a model, ORCMT can help other federal facilities meet the challenges which may threaten their survival.

ORCMT, a virtual organization, combines the research and development capabilities of ORNL with the unique manufacturing technologies of the Y-12 Plant and the pollution-prevention research and waste management of the East Tennessee Technology Park. These facilities represent over 50 years of investment in defense and energy technologies, allowing ORCMT to solve even the most complex manufacturing problems which face U.S. industry and DOD. ORCMT's services include solving tough manufacturing problems with near-term, bottom-line benefits; creating prototypes and manufacturing processes based on emerging technologies; and training workers for advanced manufacturing environments.

Core competencies include precision manufacturing; manufacturing and materials technology development; metrology and quality assurance; and energy and environmentally-conscious manufacturing. Table 2-2 shows a detailed breakdown of the core competencies. Several opportunities exist for organizations to work with ORCMT such as technical assistance programs, work-for-others program, cooperative research, licensing, user facilities, and a manufacturing skills campus.

The biggest challenge facing ORCMT is its goal to become totally self-sufficient from DOE funding. Benchmarking studies, conducted at other DOE facilities and private R&D organizations, revealed that all of these organizations rely almost exclusively on federal funding. ORCMT's transition plan to build a self-sufficient, $100-million-per-year business without government support required a change in work attitudes to overcome internal and external cultural barriers.

Internally, leaders faced the challenge of motivating its employees into believing the transition plan was achievable. First, ORCMT needed to establish its vision as a national strategy and driving force for change in other organizations. Then, ORCMT built strategic alliances, many within Tennessee, so the vision could be achieved.

Table 2-2. Core Competencies

PRECISION MANUFACTURING	MANUFACTURING & MATERIALS TECHNOLOGY DEVELOPMENT	METROLOGY & QUALITY ASSURANCE	ENERGY & ENVIRONMENTALLY-CONSCIOUS MANUFACTURING
• Prototyping • Demonstrations • Concurrent Engineering • Ultraprecision Manufacturing • Manufacturing Skills Campus	• Materials Joining • Composites • Coatings • Plating • Finishing • Materials Processing • Materials Forming • Machining Processes • Machining Systems	• Metrology • Testing • Evaluation • Diagnostics • Facility Maintenance • Control Systems	• Energy Conservation • Environmental Conservation • Industrial Water Treatment Technology

The overall objective foresaw ORCMT as a national resource which could solve difficult manufacturing problems. Externally, ORCMT's strategy possessed the politically appealing dual role of enhancing the national and economic securities.

Since its inception in 1993, ORCMT has generated more than $500 million in private-sector benefits. During FY96, the Center fielded more than 100 market-driven, technology-development teams, provided solutions for more than 500 small businesses, trained more than 1,000 people on-site, and generated more than $200 million in private-sector benefits which created or saved 400 jobs. Nearly 40% of ORCMT's work was performed within Tennessee. Figure 2-14 shows the return on federal investment and a breakdown of the benefits to private industry nationwide. Estimates predict that ORCMT's work will generate over $1 billion of private-sector benefits and create (or retain) 25,000 high-quality jobs by the year 2000.

Oak Ridge Centers for Manufacturing Technology Economic Growth

As the end of the Cold War began reducing the Nation's security forces and infrastructure, government laboratories, including ORNL, faced the challenge of retaining an adequately-skilled workforce to meet present and future national requirements. In response, ORCMT downsized and consolidated into a core force which sufficiently addresses present and future nuclear weapons requirements and significantly contributes to the economic security of the United States.

As a national resource, ORCMT's primary services include solving difficult manufacturing problems related to national and economic security; rapidly deploying products and processes to the public and private sectors; and providing a national, manufacturing-skills training center. Since its inception in 1993, ORCMT has generated more than $500 million in private-sector benefits, and estimates predict more than $1 billion by the year 2000. In addition, ORCMT has assisted nearly 3,000 small businesses in all 50 states. Assistance includes simple telephone calls; talk-through solutions; customer visits to ORCMT; site visits by ORCMT; and electronically-generated, virtual enterprise and virtual engineering via land line or satellite.

To measure the benefits to its customers, ORCMT uses a framework of measurement, information, data, and analysis. ORCMT's management and analysis processes are based upon a number of practices developed through benchmarking, experience, and continuous improvement methods. The success of ORCMT's objectives and mission is continuously measured. Each manager reviews the private-sector

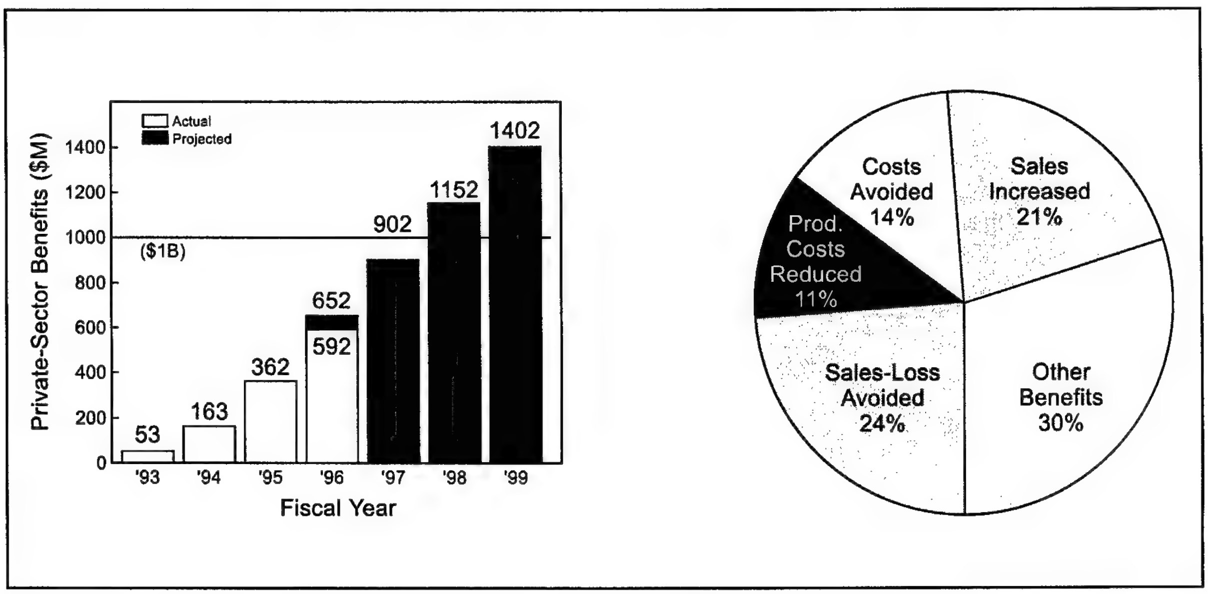


Figure 2-14. Return on Federal Investment and Benefits to Private Industry

benefits and customer satisfaction data categorized by core technology area, technology centers within each core area, and major program. In addition to the data, success stories are maintained in an electronic database which employees can access through ORCMT's internal website.

Technical Assistance Programs

ORCMT's Technical Assistance Programs (TAPs) represent an important aspect of LMES' technology transfer efforts. Designed to help small businesses, TAP provides several mechanisms for private industry to obtain technical assistance from the manufacturing, analytical, scientific research, and informational resources available at the Department of Energy Oak Ridge facilities. TAP criteria include: the company must be a small business; the company must be U.S. owned; the requested assistance must not be reasonably available in the private sector; the work cannot create intellectual property; and the work must be beneficial to DOE.

TAP, available through various technology transfer mechanisms, is designed and organized to provide customers with easy access to Oak Ridge's capabilities. Customers can access TAP by telephone (1-800-356-4USA), by e-mail (4USA@ornl.gov), through many of NIST's Manufacturing Extension Partnership Offices, or through the U.S. Navy's Best Manufacturing Practices program. ORCMT evaluates and discusses each request with the customer to determine the appropriate technology transfer mechanism. A principal investigator (technical expert), assigned to the request, contacts the customer within two work days.

The technology transfer mechanisms consist of short-term (up to four days) technical assistance at no cost to small businesses; full-cost recovery work (Work-for-Others program); user facilities where customers perform work or research on-site at an ORCMT facility; manufacturing skills training provided through the Manufacturing Skills Campus; CRADAs where specific customer interest can use matching government funds; and licensing of existing technologies. These mechanisms may be used alone or in combination to provide the needed service to the customer.

Since most requests involve manufacturing or design problems at the customer's site, TAP's most valuable resource is the technical expertise and experience of Oak Ridge personnel. TAP can access all of the technologists located at the Oak Ridge sites and corresponding facilities based upon need and availability. For other cases, TAP relies on the facilities and equipment at Oak Ridge to demonstrate an appropriate technology or result.

ORCMT has performed more than 2,200 short-term technical assistances and responded to over 1,500 information requests from all 50 states, the District of Columbia, and Puerto Rico. Data collected from customer responses indicates that TAPs generated more than $290 million in private-sector benefits and created (or retained) over 3,100 jobs (Figure 2-15). In addition, 93.6% of customers would use the TAP services again.

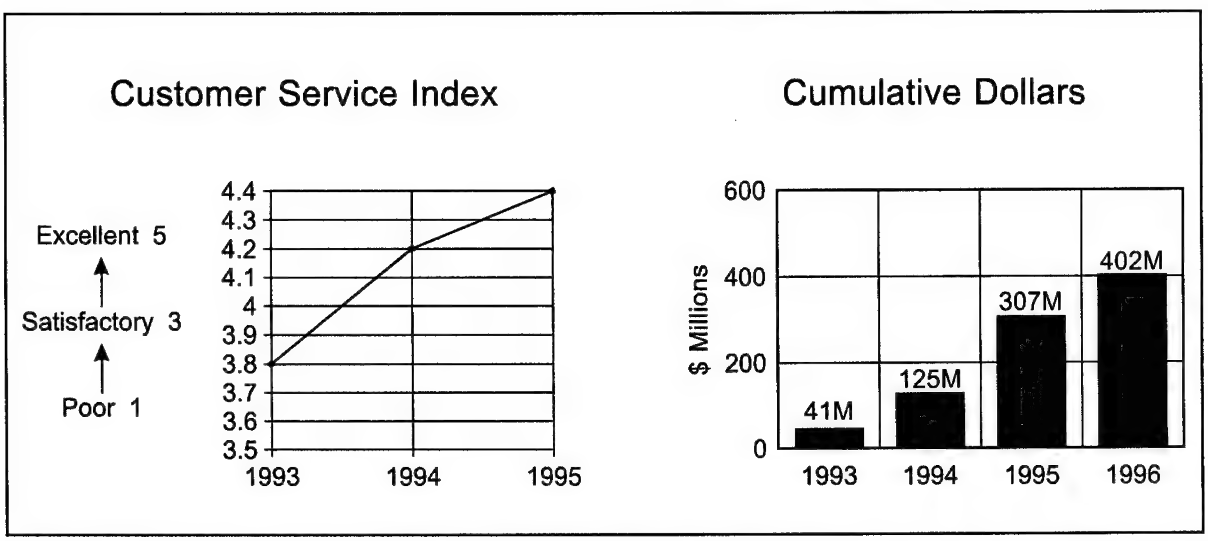


Figure 2-15. Technical Assistance Programs Reported Benefits

Train-the-Trainer Programs

As the training arm of ORCMT, the Manufacturing Skills Campus draws upon its rich resources of craft skills and knowledge at Oak Ridge. The Skills Campus provides intense hands-on and performance-based manufacturing training courses for technical educators and trainers; professional development; specific requirements; and skill enhancements. Through its Train-the-Trainer programs, the Manufacturing Skills Campus fills the technology and skill gaps of educational programs.

Needs vary across the educational and business environments. Many educators, trainers, and managers need manufacturing hands-on skills and problem-solving experience to complement their classroom or office expertise. Others, familiar with manufacturing, need refresher courses to maintain their awareness of current and future practices in the manufacturing field. Still others request assistance in developing specialized training courses for instructors at their company. To address these needs, the Manufacturing Skills Campus developed various Train-the-Trainer programs such as the Manufacturing Applications Workshops for Educators, the Advanced Manufacturing Skills Training for Technical Educators, and the Specialized Train-the-Trainer Programs.

The Manufacturing Applications Workshops for Educators provides short-term (several days to one month) opportunities for middle school, high school, and college teachers to integrate their academic expertise with hands-on skills and problem-solving experience in the manufacturing world. Through ORCMT resources, the Workshop presents an accurate portrayal of the manufacturing field and corrects any misconception about technical and vocational careers. As a result, teachers improve their ability to guide and prepare vocational and college-bound students for manufacturing careers. More than 300 educators have participated in these workshops.

The Advanced Manufacturing Skills Training for Technical Educators presents a more technical approach than the applications workshops. This training targets educators who teach manufacturing skills in secondary vocational education programs; technical colleges; adult technical vocational schools; and company training organizations. Intense, one-to-two-week classes offer educators professional skill-development training in precision machining, measurement, and maintenance technologies. The Manufacturing Skills Campus has provided training to educational facilities, government agencies, and Project Focus HOPE.

Through the Specialized Train-the-Trainer Programs, the Manufacturing Skills Campus assists organizations that lack in-house expertise, equipment, and/or facilities for training. First, the Manufacturing Skills Campus instructors develop a training curriculum package for the organization, and then train the organization's own instructional staff. This program enables the existing educators to provide training in the local geographical regions by upgrading their own capabilities.

Through these various Train-the-Trainer Programs, the Manufacturing Skills Campus offers educators enhanced skill training, customized technical disciplines, and the opportunity to use the outstanding resources at ORCMT. The Skills Campus has met the needs of GOALS 2000 Educate America Act's initiatives, School-To-Work programs, post-secondary educational institutions, and the manufacturing industry.

Travel Information System

The Travel Information System (TIS), a multiplatform application, can electronically process travel requests and authorizations. After the employee enters the travel data into the system, TIS verifies and validates the information in real-time. Next, the system electronically transfers the information to the travel services department for final processing. TIS expedites the reservation process by increasing the accuracy of the data and allowing electronic accessibility.

Prior to 1994, Oak Ridge employees submitted paper travel requests through their supervisors for written approval. Next, the paperwork was either mailed or hand-carried to the travel services department for processing. Then, the travel services department re-keyed the pertinent information into a travel database for data capture and to determine cost summaries. Common problems with this process included invalid data with the account numbers and human error when translating the information from the paperwork. The travel services department had to correct all errors before the travel request could be finalized. Transferring and validating large quantities of information created cumbersome and labor-intensive work.

First released in 1994, TIS consists of 3,000 users and includes personnel in Oak Ridge, Tennessee

(the Y-12 Plant, the East Tennessee Technology Park, and ORNL), Portsmouth, Ohio, and Paducah, Kentucky. As a multi-platform application, TIS can be launched from Windows 3.1, Windows for Workgroups 3.11, Windows 95, Windows NT, Macintosh, and Motif. In addition, TIS employs a fourth generation language (UnifAce), a Graphical User Interface, and a relational database management system (Oracle). Each environment provides point and click technology. Components of TIS include entry of the travel authorization form; approve or deny function of the authorization form; query and update capabilities; duplication of travel profiles; on-line access to General Services Administration (GSA) rates; and electronic mail notification.

Upon entering TIS's travel authorization module, the user can create a new form; view and update a previously-stored form; or produce a duplicate from a previously-stored form. Within the travel approval module, the user can view any forms which were previously approved or denied; or view travel authorizations in queue for approval. Action may be taken to electronically approve or deny any outstanding travel authorization forms. In the GSA module, the user can look up the diem rates of designated cities. TIS allows the user to process, track, and maintain the records of all travel forms.

Employees do not need any formal training to operate TIS. Instead, the user-friendly system provides an on-line user guide. TIS has reduced the average process time of travel authorization forms from about two weeks to two days. With approximately 73,000 travel forms already processed through TIS, Oak Ridge anticipates an annual efficiency savings of $200 thousand.

Work-for-Others Program

ORCMT continues to conduct an aggressive Work-for-Others (WFO) program that provides full-cost recovery for work performed, helps maintain critical core competencies, and assists in reducing general plant overhead. Simply defined, WFO is work performed at DOE facilities but funded by a non-DOE source. DOE charges the customer the absolute minimum in administrative costs based on a full-cost recovery. Initiated in 1993, the WFO program benefits U.S. industry and other government agencies by providing scientific research, manufacturing skills, and technological competitiveness. ORCMT's efforts to streamline its WFO program include improving the contracting mechanism, simplifying the payment methods, assisting business developers in acquiring new business, and providing easier assessability of its facility for customers.

Like most government industrial sites with similar programs, ORCMT offered its customers exceptional technical performance but a time-consuming administrative process for entry into the WFO program. Completion of the administrative process, filled with numerous forms and susceptible to delays, usually took four to six months after the customer's request. ORCMT regarded this timeframe as unacceptable. Getting customers' products and processes introduced into the market place required a timely response by the WFO program. In response, ORCMT pursued an aggressive continuous improvement initiative to streamline the administrative process, shorten the cycle time, and eliminate obstacles.

After reviewing its administrative process from request to approval, ORCMT eliminated unnecessary forms and simplified cumbersome ones. In addition, unproductive steps were omitted while other steps were performed in parallel or in advance where allowable. With approval by DOE, ORCMT revised the contracting mechanisms so customers could have a better understanding of the terms and conditions when working with DOE facilities. By expanding the areas where visitors could go without an escort, ORCMT improved the accessability of its facilities for WFO customers. This effort doubled the area and made the entire east end of the facilities accessible to visitors. ORCMT also designed a business-development toolkit which assists business developers in acquiring new business. The toolkit includes information on ORCMT services, industrial selling, cost estimating, proprietary information, licensing, and other valuable information needed to increase revenue.

Since implementing these improvements, ORCMT has reduced its administrative process to six days, and substantially decreased its administrative costs. In addition, the number of firms using ORCMT's WFO program has increased by 300%.

Section 3

Information

Design

Casting Simulation

ORNL has established a casting simulation facility and an integrated approach to manufacturing cast components. This approach combines manufacturing experience with modeling technology in a way that streamlines the manufacturing of a cast product. ORNL's cutting-edge technology also provides strong technical support and manufacturing experience to support the entire process from product concept to production.

The integration of various CAD and design tools provide ORNL with the flexibility to efficiently design the part and simulate the casting process. ORNL combines its simulation environment, ProCAST, with various design software models such as PATRAN, IDEAS, IFEM, GFEM, ProEngineer, ANSYS, ARIES, and ANVIL. Using its manufacturing and modeling technologies, ORNL provides simulation analysis capabilities involving solidification through conjugate heat transfer, micromodeling, residual stress, radiation heat transfer, electromagnetic effects, and buoyant particle tracking.

Typically, ORNL electronically processes the part definition of a casting to create an analysis model. Casting-simulation studies then determine the most effective boundary conditions for ensuring optimum molten metal flow, proper filling of the mold, and solidification of the cast product. This method usually reduces segregation and radiographic results to an acceptable level. Quite often, the simulation creates a new design or prototype, or finds a near-net or net shape cast product to replace a wrought product. By using an integrated manufacturing approach, ORNL produces high-quality, sound castings.

ORNL's unique technology and capabilities guide the design of the part and the casting process from concept to final product. Costly trial-and-error casting runs are eliminated by simulating the process and optimizing the design features, prior to an actual casting run. Potentially reducing costs by up to 50%, ORNL has realized benefits in cost reductions, cycle-time reductions,and material-waste reductions.

DNA Biosensor Microchip

Researchers at ORNL have devised a self-contained miniature deoxyribonucleic acid (DNA) biosensor to detect specific DNA targets. The biosensor will detect hybridized DNA without any external monitoring or signal transmission. Biosensors of this type have potential applications in medicine, forensics, agriculture, and environmental bioremediation. Ultimately the size of a transistor chip, the biosensor microchip incorporates multiple biological sensing elements (e.g. DNA probes), excitation microlasers, a sampling waveguide equipped with optical detectors (fluorescence and Raman), integrated electro-optics, and a biotelemetric radio frequency signal generator.

Semiconductor microlaser arrays are incorporated into a device which has oligonucleotides of specific DNA sequences attached to the surface. Free DNA sequences with fluorescent labels then are allowed to hybridize to those oligonucleotides with matching homologic sequence. When illuminated at its optimum wavelength, the fluorescently-labeled DNA will emit light. The microlasers contained in the device will illuminate each pixel on the surface, and the detector array will identify pixels with attached fluorescently-labeled DNA sequences.

DNA biosensor technology can rapidly detect microorganisms from multiple environmental samples. A sensitive, accurate sensor has been developed to identify a Pseudomonas organism for use in bioremediation and the human p53 cancer tumor suppressor gene. Other applications under development include a biosensor for tuberculosis, human immunodeficiency virus, salmonella, legionella, giardlia lamblia, lyme disease, hepatitis, toxoplasmosis, and biological warfare detection.

Induction Motor Performance Evaluation Tool

The Induction Motor Performance Evaluation Tool 96 (IMPET96) is a software program which computes the derived parameters of a motor such as efficiency, load, and current. IMPET96 can evaluate existing motor systems, and help determine whether adjustments or replacements are needed.

The motor's nameplate supplies the required input for operating the software. The only input which the user needs to measure is the operating speed of the motor. IMPET96's calculations are modeled after a modified version of IEEE's Equivalent Circuit.

Voltage measurements are often difficult and quite dangerous to measure in the field. Since IMPET96 can perform an evaluation without using a motor's voltage, the program eliminates this situation for the user. IMPET96 also provides an advanced operating mode option which allows the user to adjust for variations in nameplate data by overriding the program's assumptions. IMPET96 can currently be licensed through the Technology Transfer Office at ORNL.

Currently, an advanced version called IMPET2000 is being developed. IMPET2000 will provide a more detailed performance analysis of motor systems, and will be able to validate or detect any inaccuracies in nameplate data. This software program may also be able to compute nameplate efficiency by having the user take measurements at three different load levels.

Intelligent Tutoring Systems

ORNL's integrated training (Figure 3-1) exists in a variety of learning environments and applications. These applications range from simple browsers to adaptive and intelligent tutoring systems. ORNL is currently working on intelligent tutoring systems which can separate the knowledge base from the training application. By separating the knowledge base from the application, learning aids can be developed incrementally. Over time, the initial knowledge base can be expanded without affecting the training applications. This reusable training data approach allows expert knowledge to be captured as it is identified, without specifying exact requirements or delaying the development of an end product because of resource shortages. In addition, this approach works regardless of whether the eventual system becomes a browser, a tutorial, an expert, or a combination of applications.

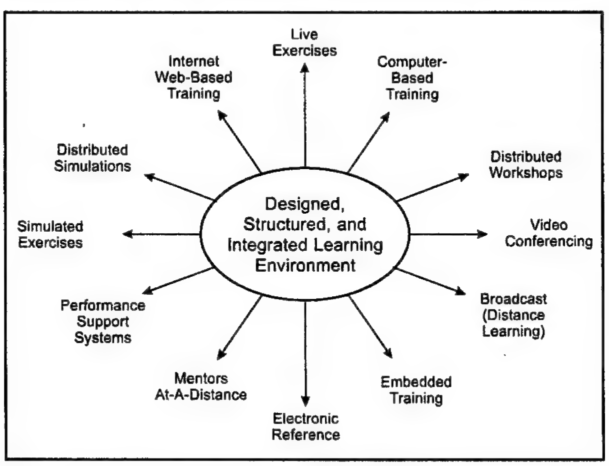


Figure 3-1. Integrated Training Environments and Applications

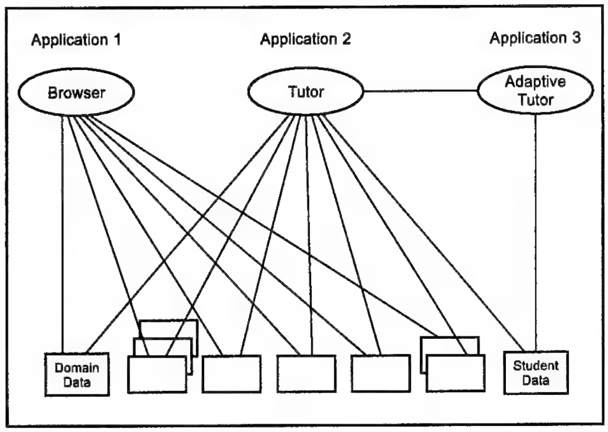


Figure 3-2. Approach to Reusable Training Data

Through the reusable training data approach, ORNL first gathers the expert knowledge for the database and then builds access methods to meet the users' needs. Figure 3-2 illustrates ORNL's approach to reusable training data. Today's databases can handle text, images, audio clips, graphics, and limited video. Modifications to the data need not affect the application. Applications can be written in hypertext markup language, authoring systems, programming language, or in the database's own application. Numerous applications are possible with a single database and can serve many purposes including reference, learning, help, certification, and instructional feedback. In addition, applications can be housed on a CD-ROM or a server, and can be accessed from a stand-alone PC, a local network, or over the Internet. The ease of configuration management and updating the knowledge base makes Internet and networked applications particularly attractive.

Power Converter/Inverter

ORNL has developed a new, advanced electric power converter/inverter. This power inverter provides a much higher power density, produces less electromagnetic interference, and works more efficiently than a conventional inverter. In addition, ORNL's inverter is two to three-fold smaller and lighter than its counterpart.

In an electric vehicle, the power available to the vehicle's electric drive motor must be varied to allow the motor to adjust to the varying speeds and loads encountered during normal operations. Inverters convert DC power into AC power. An electric vehicle's DC power, stored in batteries, needs to be converted into AC power which is more efficient at running the electric drive motor.

To be practical for commercial electric vehicles, an inverter must meet critical factors such as power efficiency, reliability, size, weight, and electromagnetic interference. Conventional inverters use six power switches to achieve the desired voltage output. ORNL's inverter uses three small auxiliary switches which temporarily and briefly deliver current and then reroute it back to one of the six main switches. This diversion, which lasts a few microseconds, produces a zero voltage across the switch and helps reduce power spikes from occurring. The result is an increase in reliability and a decrease in electromagnetic interference problems. The soft switching also decreases power consumption of the inverter. Lower power consumption reduces the need for heavy heat sinks, which in turn reduces the weight of the inverter.

Because it can smoothly change the voltage and current of a motor, ORNL's inverter reduces the possibility of electric motor failures caused by insulation breakdown and bearing overheating. At 11 kilowatts per kilogram, the inverter's power density exceeds the Partnership for New Generation of Vehicles' goal of 5 kilowatts per kilogram. In addition, the inverter operates at 98% efficiency at high speeds and 80% efficiency at low speeds. Conventional inverters supply 94% efficiency at high speeds and 60% to 70% at low speeds.

ORNL's power converter/inverter offers many benefits for hybrid and electric vehicles. Other potential applications include improving the operating efficiency of air conditioners and heat pumps.

Thermal Analysis and Diffraction

The Diffraction and Thermophysical Properties User Centers of ORNL's High Temperature Materials Laboratory (HTML) offer a unique combination of facilities for materials research and process development. Here, U.S. companies can work with highly-trained technical personnel and state-of-the-art equipment, free of charge, provided all results are published and benefit industry as a whole.

Typically, when studying high temperature materials processing, researchers only examine the initial and final state of the materials at room temperature. This approach does not gather any detailed information during the actual processing. High temperature in-situ studies of processing have shown that improved understanding and control of processes can be achieved through high temperature characterization techniques such as x-ray and neutron diffraction coupled with thermal analysis. HTML facilities can provide extensive in-situ characterization of materials at temperatures up to 1600°C for almost any atmospheric condition and at higher temperatures in a vacuum environment.

Although computer modeling has provided the metals processing industry with improved quality and significant savings, the thermophysical property data is generally unavailable, particularly at temperatures above 1000°C. HTML facilities can determine the thermophysical properties of alloys up to and including the molten range. As a result, this data has helped ORNL and industry develop, verify, and modify metals processing models that save time and money.

Materials studied at the HTML facilities include structural ceramics, ceramic precursors, ceramic and metal matrix composites, super alloys, superconducting materials, carbon materials, and carbon fiber composites. The major centers consist of the diffraction and the thermal analysis facilities.

The diffraction facilities can extensively characterize anisotropic thermal expansion, solid state reactions, phase transformations, reactions of starting materials, oxidation kinetics, and crystallization from the melt. The thermal analysis facilities can characterize the reaction or decomposition temperatures, heats of formation, heat capacity, bulk thermal expansion, thermal conductivity, and reactions with environmental gases.

Virtual Concurrent Engineering

ORCMT's Concurrent Engineering Center (CEC) promotes the concurrent engineering philosophy by centralizing Oak Ridge's extensive integrated computer technologies. Through its resources, CEC can address an entire manufacturing process from concept through product realization.

By combining technical experts with integrated computer applications, CEC can develop, visualize, and analyze proposed designs in a 3-D, computer-generated image or model under simulated conditions prior to the fabrication of a prototype. As a result, designers, manufacturers, and customers benefit from more effective and productive communications, and the manufacturing process becomes streamlined. Available CEC applications include virtual environments, computer visualization and simulation, product modeling, electronic product data exchange, and advanced numerical control for material removal.

ORCMT estimates the typical savings from its virtual concurrent engineering at 40%. Key elements in the savings include significant reduction in detailed design and post release engineering; leverage of the solid model in downstream applications; reduction of downstream changes; optimization of parts; and elimination of trial parts.

Test

Biological Threat Detector

Identifying potentially-infectious bacteria, quickly and accurately, poses a challenge to researchers in a field environment. Typically, researchers collect a sample, send it back to the laboratory, have the sample grown in a cell culture, and wait for a technician to interpret the results. This method furnishes subjective results in a time-consuming manner.

Researchers at ORNL's Chemical and Analytical Sciences Division have developed the biological threat detector which can detect and identify numerous species of microorganisms at the unit cell level in a single analysis. This immunoassay technique uses structural resonances to determine the precise diameter of transparent immunospheres which contain a fluorescent dye. Researchers then coat different diameter spheres with antibodies that are specific to a bacteria. The diameter of the immunosphere identifies the antibody coated to it. After an incubation period, researchers could identify the stained microorganisms by observing the size of the antibody-coated immunosphere to which they were attached.

The biological threat detector could be used as a portable, briefcase-sized, manually-operated instrument. The same principles could be incorporated in a completely-automated, stand-alone instrument based on flow cytometry methods with only a modest increase in size and complexity. Applications include microorganism identification by military personnel or sample collection by field inspection teams.

Fiber Optic Sensors

ORCMT has been investigating innovative uses for fiber optic technology in sensor-based applications. Researchers have been focusing on the application development of silicone rubber optical fibers. These compliant materials can be embedded in various matrices, conforming to the environment in which they are located, and sense bends, stretches, distortions, twists, ruptures, vibrations, compressions, moisture content, and excessive temperatures.

Fiber optic sensors can be characterized as intrinsic and extrinsic. Intrinsic fiber optic sensors use the properties of the fiber as part of the sensing mechanism. Extrinsic fiber optic sensors use the fiber, itself, as a way to transport information in and out of the sensing elements. Experienced in both types, ORCMT has devised sensor-based applications such as weighing vehicles in motion and transporting high-power laser beams.

Fiber optic sensor technology provides many advantages for the defense community. Benefits include its immunity to electromagnetic noise; resistance against vibration damage; low conductivity of electricity and heat; compact size; and affordability. Fiber optic technology is also compatible with advanced applications because it can be coupled with non-linear optical materials, fast-switching optical components, and ultra-high-speed communications systems. In addition, fibers can be fabricated from high temperature materials, such as sapphire and silica, for embedment into advanced composites, airframes, and hulls.

Mechanical Properties Microprobe

Hardness represents an important attribute of materials. Traditionally, a material's hardness is determined by indentation testing using optical microscopy to measure the contact area. When characterizing hardness in thin film, multiphase materials (e.g. superconductors, ion implanted sur-

faces), hardness needs to be measured on a small scale. Optical methods, however, do not have sufficient resolution to measure indents generated at very low loads (< 20 mN) or at shallow depths (< 250 nm). Since August 1995, ORNL's HTML has been using a mechanical properties microprobe (MPM).

MPM directly measures the indenter depth during the indentation testing. As a special microhardness tester, MPM can operate at very low loads from 0.02 to 12 grams. Researchers use a three-sided Berkovich diamond pyramid to make an indentation in the sample. Generated electromagnetically, the indenter load can be controlled by varying the current in the coil surrounding the indenter shaft. A capacitive sensor measures the indenter shaft displacement and relates the information to the contact area by using the appropriate geometrical relationship for the indenter. Consequently, the load and displacement can be continuously measured during the indentation process. Unique to its tester, HTML's MPM can be operated with specialized indenter configurations such as spherical and flat punches in addition to the standard Berkovich diamond tip.

The resulting data from MPM can be used to calculate the hardness (from the loading curve) and elastic modulus (from the unloading curve). MPM has been successfully used to measure mechanical properties of thin and thick films, surface modified layers, and multiphase materials; deflection of microbeams as related to electronic devices; interfacial properties in composites for debond energy, residual stress, and sliding shear stress; diverse materials such as martensitic and austenitic phases in steel; thermal barrier coatings; and fiber push-in tests on small fibers.

Microcantilever Devices

Microcantilevers represent a new category for sensors and biosensors. Constructed of silicon, the devices are generally shaped like a diving board with an approximate length of 100 micrometers. Advantages include miniature size, high-degree of sensitivity, simplicity, low power consumption, low manufacturing cost, inherent compatibility with array designs, operable in air or liquid, and remote location operations with wireless reporting capabilities.

The extremely low mass of the device allows it to sense perturbing forces because of the adsorbed masses at the picogram level; the viscosity of a gas or liquid over several orders of magnitude; and the acoustic and seismic vibrations. Special coatings on the silicon will adapt the cantilever to sense relative humidity, temperature, mercury, lead, ultraviolet radiation, and infrared radiation. By using current micromachining technology, multiple arrays could be used to make multielement or multitarget sensor arrays involving hundreds of cantilevers without significantly increasing the size, complexity, or overall package costs.

Microcantilevers could revolutionize sensor technology because of the low cost, high sensitivity, and versatility. Potential applications include detecting and identifying pathogenic bacteria and toxins in only minutes (instead of days); detecting biological warfare agents under battlefield conditions; and detecting chemicals in the environment for cleanup monitoring. Oak Ridge designed two microcantilever prototypes (one for mercury detection and one for infrared imaging) which received the I-R 100 Awards in 1996.

Miniature Water Quality Laboratory

ORCMT is developing an apparatus which can provide a rapid, portable, inexpensive method to certify water potability. Typical water-quality analysis involves collecting samples, transporting the samples to a laboratory, and analyzing the samples with on-site equipment. Results usually take days to obtain.

The portable device under development (Figure 3-3) will use current technology based on the microbial reaction of luciferin, luciferase, and magnesium ions (prepared reagents) to adenosine triphosphate (ATP) from any living organism. During analysis, the researcher mixes the water sample with the prepared reagents. If the sample emits a fluorescent light, the researcher knows that ATP is present, the sample contains living organisms, and the water is contaminated.

About the size of a transistor radio, the miniature water quality laboratory will incorporate the necessary electronics; an easy, low-technology control panel; and an LED information panel. The bulk of the unit's volume will be determined by the water sample size as set by industry's water analysis standards.

ORCMT's miniature water-quality laboratory will provide an efficient and quick method for analyzing water quality; enable personnel to operate the equipment with minimal training; omit the need for central facilities or utilities; and offer accessibility for field testing. Advantages over conventional laboratory methods include reduced size and weight; full automation; mobility; and minimal consumable usage.

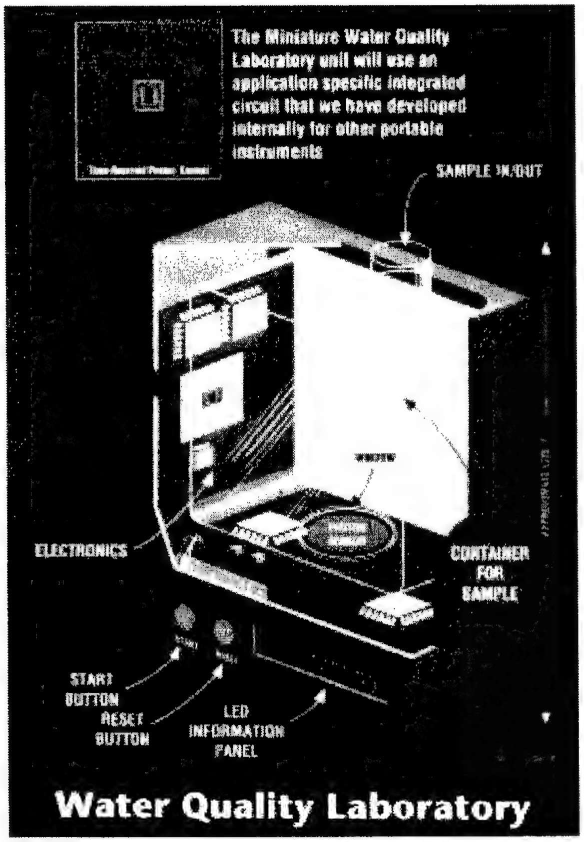


Figure 3-3. Miniature Water Quality Laboratory

Pump Flow Test Loop Facility

ORNL's Pump Flow Test Loop facility, a multipurpose modular laboratory, provides versatile fluid system conditions for configuring and testing motors, pumps, valves, flow metering devices, and other components. Sensors within the fluid system can monitor, record, and analyze various parameters such as pump and motor vibration; fluid flow; temperature; and output torque. Specialized instrumentation allows researchers to perform detailed, dynamic signal analysis on pumping systems beyond normal, steady-state monitoring.

The flow loop system provides a maximum flow capacity of 3,500 gallons per minute and a working pressure of 100 pounds per square inch. The supplied motor power (three-phase, 480 volts, and 300 amps) contains a starter/circuit breaker which can be programmed to any setting within the amperage range. A versatile valving setup allows the system to be configured for various testing situations such as complete shutoff, very low flow, and full pump runout flow. In conjunction with the Motor Test facility, flow loop pump motors can be calibrated for flow loop research. Recorded data acquired at the flow loop under realistic operating scenarios can be used at the Motor Test facility to test motors under simulated conditions. In addition to pump and motor systems, the pipe system uses a modular design which allows researchers to remove sections, install flow metering devices or valves, and calibrate them against the system.

The Pump Flow Test Loop facility is used also when conducting the fluid and thermal system training for operations personnel. The training explains the overall system, offers hands-on experience, shows methods for using the system efficiently, and provides insight for problem solving.

ORNL's Pump Flow Test Loop facility offers data analysis and unique, versatile testing. Applications include pump and motor efficiency; hydraulic stability; actuator performance; motor current and power signature analysis; pump flow design validation; and non-intrusive check valve diagnostics. ORNL realized a $100 thousand per year savings from a project with the Fusion Energy Building. By evaluating and changing the pumps, personnel increased the flow efficiency of the chilled water system. Vibration problems were also solved which reduced operator stress and eliminated the need for hearing-protection equipment.

Rapid Machine Characterization

The Oak Ridge Y-12 Plant has developed the Vector Displacement Interferometer (VDI) which offers an alternative method for mapping positioning errors on coordinate measuring machines and machine tools. The VDI (Figure 3-4) provides a simpler and faster process than traditional laser trackers.

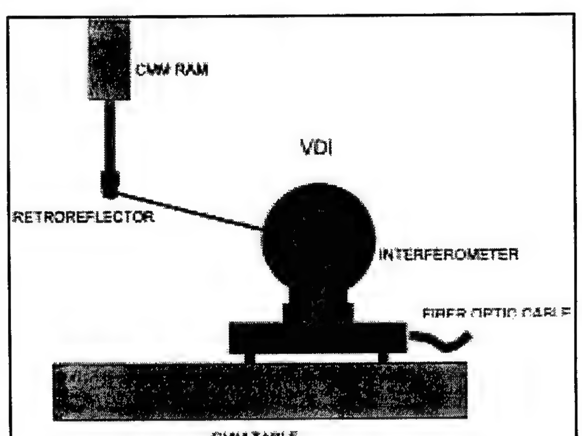


Figure 3-4. Vector Displacement Interferometer

Conventional mapping techniques use an expensive and time-consuming process, and require the user to be trained in the operation of specialized equipment. The user must map the three translational and three rotational motion errors of each slide; measure the squareness errors between the slides; and then calculate the positioning error from the error components by using rigid body motion equations.

The VDI provides a different approach. The user measures all machine displacements directly with the VDI. By taking three sets of measurements from three separate observation points, the user can mathematically combine the values to calculate the x, y, and z positioning error components. Unlike conventional laser trackers, the VDI does not contain a laser. Instead, a fiber optic cable delivers the laser beam to the device. This feature reduces the device's size and eliminates heat as an error source. In addition, the small size allows the user to place the device directly on the table of the machine being mapped.

From its relative ease and speed, the VDI mapping process provides additional benefits. Users can generate uncertainty estimates, use 3-D interpolation directly to compensate for positioning errors, eliminate rigid body motion assumptions, and produce slide parametric error estimates from the x, y, and z positioning error components in diagnostic situations.

The Oak Ridge Y-12 Plant currently runs qualification experiments with the VDI equipment. With its efficiency, portability, and versatility, the VDI will allow users to explore new applications.

Residual Stress Management

Residual stress knowledge provides a critical key to component life prediction and failure analysis. Both macro (long range) and micro (short range) residual stresses can be independently characterized by diffraction methods. As a national resource for residual stress knowledge, the High Temperature Materials Laboratory (HTML) at ORNL uses various diffraction methods that are applicable to polycrystalline materials including alloys; ceramics; thin films and coatings; and composites.

Neutron diffraction macro residual stress mapping, a unique capability at ORNL, uses the highest flux research reactor in the United States. This capability addresses design, life prediction, and component failure issues. In addition, neutron powder diffraction methods can measure micro residual stresses as a function of temperature.

X-ray diffraction typically determines near-surface measurements. However, HTML has developed special x-ray diffraction capabilities to solve problems associated with curved-surface measurements (down to a 6 millimeter radius) and non-destructive subsurface stress gradient measurement in ground ceramics and coatings. Additional x-ray diffraction capabilities include two dedicated, four-axis, high-precision goniometers; 2-D and 3-D strain and texture mapping; and grazing incidence x-ray diffraction for subsurface and thin film residual stress profiling.

HTML's Residual Stress User Center offers organizations an opportunity to work with experienced personnel, state-of-the-art facilities, and high-precision equipment. Capabilities provided by the Center include finite element modeling; quantitative crystallographic texture analysis; elastic moduli analysis; retained austenite and phase analysis; depth profiling of stress; stress dependence on temperature; and load transfer between phases of composites.

Customers can utilize the Residual Stress User Center at no charge provided their research work is non-proprietary and co-published with ORNL. For proprietary work, the Center charges a fee. ORNL has assisted many industrial, government, and academic organizations in material characterization and residual stress analysis.

Production

Analytical Instrumentation and Sensors

The Oak Ridge Y-12 Plant has developed numerous analytical instruments which can monitor manufacturing processes and effluents. These include a uranium monitor and a mass spectrometer. Designed for field usage, these small, portable units can quickly monitor environmental conditions such as detecting uranium in water samples or identifying the elemental and isotopic composition of gaseous samples.

Traditional sampling methods involve gathering water or air samples from numerous field locations throughout the day and sending the samples to a laboratory for analysis. The results would then be issued in a report and forwarded back to those responsible for maintaining the water or air quality at the test sites. With traditional methods, several days would elapse before a possible contaminant could be identified and addressed.

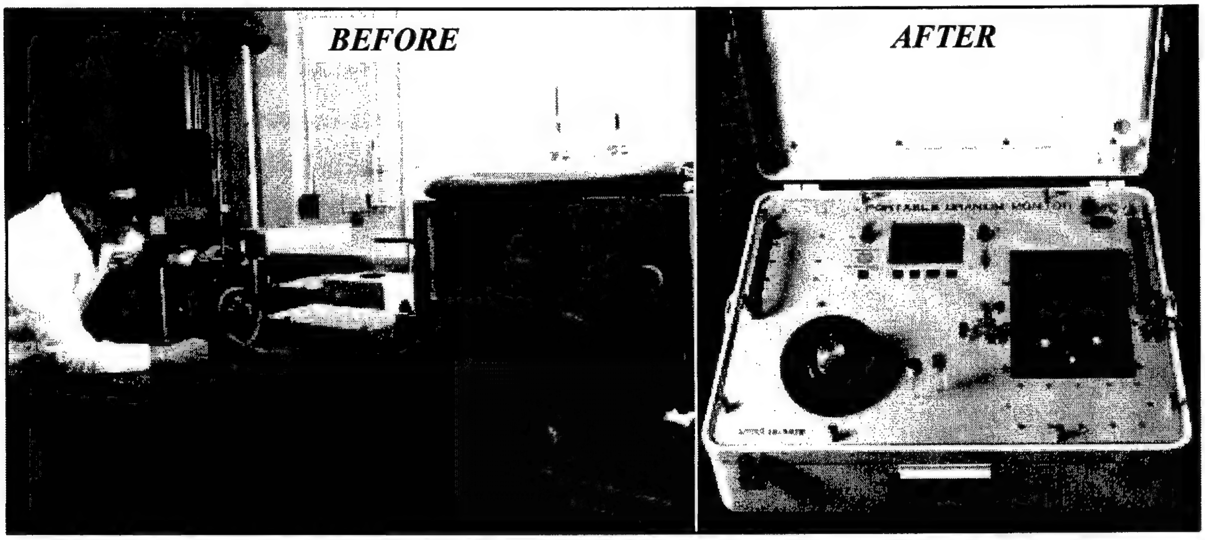


Figure 3-5. Uranium Monitor

Y-12 devised a portable uranium monitor to replace the traditional bench-top laboratory analysis system (Figure 3-5). Developmental steps included identifying the specific functions used in traditional systems; designing and testing an application-specific integrated circuit, user software, and a simple user interface; and fabricating all mechanical components. As a result, Y-12 successfully built a working prototype which can function as a portable or fixed-station monitor. In addition, the unit can be modified for detecting environmental pollutants such as polychlorinated biphenyls, poly nuclear aromatics, hydrocarbons, rare earth elements, and radioimmunoassay replacements. Y-12 estimates that the uranium monitor could be manufactured for less than $10 thousand.

Similarly, Y-12 has completed a miniaturized version of a mass spectrometer. This portable unit could be used to detect environmental contaminants such as exhaust gas, freon leaks, volatile organic compounds, and chemical warfare agents. In addition, Y-12 has been developing sensors for hydrogen peroxide, chlorinated solvents, hydrogen, fuel in water, industrial hygiene metals, and nitrogen oxides.

Oak Ridge has recognized that traditional detection methods can be costly and time consuming. By monitoring for possible environmental contaminants with portable monitors and sensors, users can benefit from real-time information, savings in utility use, improved inventory control, greater product yield, and increased product quality.

Automated Ammunition Handling and Transfer

The Army's next generation 155 mm field artillery system, known as the Crusader, will consist of a self-propelled howitzer (SPH) and a resupply vehicle (RSV). The current reloading process requires personnel to leave the vehicles' protective stations and perform a laborious, time-consuming procedure. ORNL has extensive expertise in developing remotely-operated equipment for use in hazardous environments. Working with the Army's requirements, ORNL has designed a system (Figure 3-6) for the Crusader which automates the fuzing, handling, and transfer of ammunition.

ORNL's system features automated fuze insertion, weighing, and ammunition identification which reduces processing time and increases the input data accuracy to the system's onboard computer. In addition, a six-degree-of-freedom robotic arm enables the two vehicles to dock so personnel can transfer ammunition from the RSV to the SPH without leaving either vehicles' protective station. Once the RSV is within range, an automated docking system controls the autonomous docking between the robotic arm and the docking port by using machine-vision techniques. The time required, using the automated docking system compared to the manual docking procedure, was reduced by a factor of more than four.

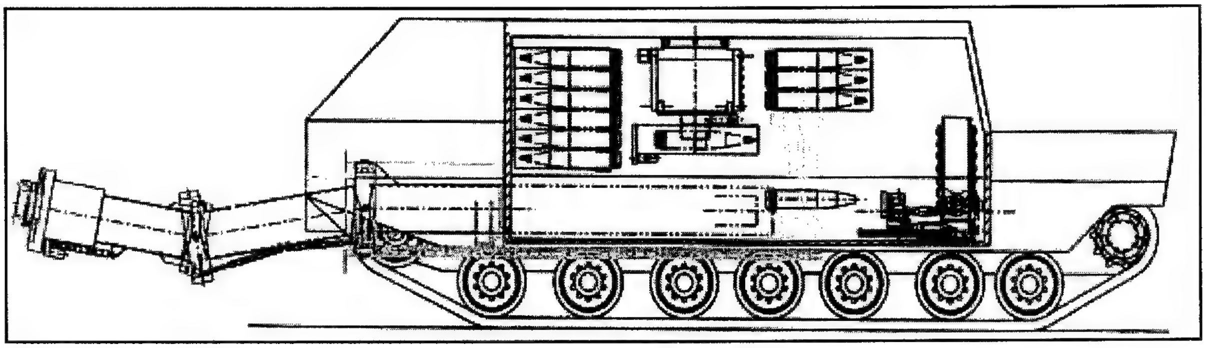


Figure 3-6. Concept Drawing

ORNL's automated system demonstrates the flexible automation technology needed in today's changing manufacturing paradigm. With the success of ORNL's $15 million developmental effort, the Army project has now been transitioned to the private sector for vehicle prototype development.

Electroforming Advisor System

Electroforming can produce freestanding parts by cathodically depositing metal on a mandrel. The same technique allows adherent protective coatings to be applied to a part. By default, electroforming precisely replicates the mandrel surface's contour. However, the precise control of the oppositecontour is a design and control issue. Current electroforming technology relies on multiple iterations of tooling design and fabrication; experimental tests; evaluations; and a highly-experienced expert.

ORCMT has developed the Electroforming Advisor System. The system offers a more robust method for handling various geometries and situations; improves processing time; performs multiple iterations computationally; and automatically optimizes the cell geometry and electroforming parameters. The system replaces physical, trial-and-error methods; eliminates several discrete modeling and analysis steps; and reduces the waste generation of spent electroforming electrolytes.

ORCMT's Electroforming Advisor System will allow companies to produce larger quantities of complicated pieces at a fraction of precision machining costs. The pieces can also be manufactured at precise tolerances with less manpower requirements. For actual experimental trials, the Electroforming Advisor System can reduce environmental costs by 90% and turnaround time and costs by 80% compared to current technology.

Enhanced Gun Bore Protection

ORNL is exploring new coatings and deposition methods for replacing the hexavalent chromium coatings in 120 mm gun tubes on M256 Abrams tanks. Although used as an electroplated bore coating in most gun barrels, hexavalent chromium creates environmental problems. The replacement coating should be environmentally safe, be able to withstand the 3500°K flame temperatures of modern high-impulse propellants, and provide a gun barrel life of 1500 rounds.

ORNL has identified rhenium and molybdenum-rhenium alloys as potential plating replacements. The study indicates these materials would be able to withstand the gaseous contaminants and high temperatures of modern high-impulse propellants. In addition, ORNL is evaluating deposition methods for ease of fabrication, physical characteristics of the lining, and cost considerations. Methods being addressed include physical vapor deposition (magnetron sputtering) and thermal spray deposition (plasma spraying). Although the study currently focuses on smooth bore gun barrels, ORNL anticipates the research to include rifled barrels in the near future.

Florescence Thermometry

Florescence thermometry allows scientists to measure temperature in hostile environments, mobile surfaces, and inaccessible locations. Over the past decade, Oak Ridge has pioneered many developments in fluorescence thermometry. This method relies on temperature-dependent fluorescence materials called thermographic phosphors. Examples of thermographic phosphors include rare-earth-doped (activated) ceramics or compounds such as

Group III metal oxides and metal oxysulfides; orthophosphates; vanadates; yttrium aluminum garnet; and fluorogermanates.

Thermographic phosphors are applied to the surface of the object by an appropriate method such as sputtering, vacuum plasma, or flame spray. Next, a laser beam, directed by optical fibers, excites the florescent properties of the thermographic phosphors. Each phosphor then generates temperature-dependent, narrow-band optical emissions which spans several hundred degrees. A light detector transmits the emissions signal back to an analyzer where a scientist calculates the temperature correlation. Since the emissions' fluorescence lasts tens to hundreds of microseconds, both the wavelength and lifetime selection in the measurement system can adjust for extreme blackbody background light or the effects of rapidly moving surfaces.

By optimizing fluorescence thermometry, Oak Ridge offers a unique capability to its customers. Applications for measuring temperature include high-speed rotating surfaces; ambient and cryogenic liquids; on-line galvanneal steel; and internal components of turbine and combustion engines. In addition, lightweight, rugged instruments for ground, air, and space vehicles could possibly be designed and fabricated by using low-cost fibers and digital electronics to process the signals generated from fluorescence thermometry.

Indoor Air Quality

The Oak Ridge Y-12 Plant offers on-site surveys and indoor air quality (IAQ) analyses for flue gas, cooling-tower water quality, sick-building syndrome, and hazardous work environments. The IAQ team consists of biologists, chemists, American Chemical Society-certified technicians, and a certified industrial hygienist. This diverse staff's credentials include averaging 23 years of experience; authoring more than 125 technical publications; holding two patents for mass spectrometry environmental analysis; and winning the R&D Magazine I-R 100 Award for innovative development work on the Fourier transform infrared mass spectrometer.

With a fully EPA-accredited laboratory, the IAQ team uses state-of-the-art field instruments and mass spectrometers to measure various substances such as CO, NO, NO_x, radon, asbestos, lead, microbes, dust, and volatile organic compound emissions. In addition, the IAQ team can efficiently identify IAQ problems; develop practical, cost-effective plans for solutions; address worker health and safety concerns; reduce the possibility of IAQ-related work disruptions; and minimize potential liability.

Intelligent Welding

Modifying the process controls of a welding system tend to be reactive-driven and are usually implemented after a statistically-significant number of defects have occurred. In addition, inspectors typically must take the welding system off-line before testing the quality and integrity of its process. Current work at ORCMT focuses on Intelligent Welding which integrates the inspection into the manufacturing welding process. By using a real-time assessment of the welding process and enacting the feedback control techniques, the end product's quality can be improved.

Intelligent Welding focuses on fabricating a quality, first-run, weld-manufactured product with high repeatability. Key challenges include sensing and diagnosing the product's on-line state; operating in an extremely harsh environment; and the high-speed processing requirements. ORCMT has been investigating optical methods for visualizing and tracking the weld quality during Gas Tungsten Arc Welding, Electron Beam Welding, and Laser Beam Welding. Researchers have demonstrated limited control capability with Gas Tungsten Arc Welding. ORCMT has also been conducting manufacturing performance tests on wire speed, welding current, and welding voltage sensors for Gas Metal Arc Welding.

ORCMT continues to investigate and develop Intelligent Welding techniques. These techniques hold promise for addressing industry-wide problems associated with post-process defects and low production quality.

Laser Radar

By combining range imaging technology with amplitude-modulated laser radar technology, ORNL has developed a method for measuring the arc lengths along complex, body surface contours. This innovation utilizes active laser ranging equipment, combined with mirrors and calibration, and image analysis procedures.

Laser radar operates by measuring the phase and amplitude of a reflected modulated laser beam. Because only one optical path is required between the sensor and the subject, distances to the surface

can be accurately measured to within 1 millimeter. Multiple images are combined by integrating information from different virtual viewpoints. By interposing reflecting surfaces into the optical path, any number of images can be created. This method also allows accessibility to unusual contours such as saddle-shaped or wedge-shaped crevasses.

Although the laser radar measurement technique could be applicable in various engineering and scientific fields, this technique would be particularly useful in anthropometry, the study of human body measurements. Tailors, artists, and scientists rely on anthropometry for their livelihoods. By using a single camera with several mirrors, the technique could quickly calculate an accurate assessment of body sizes and shapes without using manual tape measurements.

Machining and Inspection Research User Center

The Machining and Inspection Research User Center (MIRUC), located at ORNL's High Temperature Materials Laboratory, comprises nine separate laboratories. MIRUC offers researchers an opportunity to work with experienced personnel, state-of-the-art facilities, and high-precision grinding equipment. Capabilities provided by MIRUC include high-temperature material manufacturing; complex ceramic component grinding; wear and friction studies on lubricants; material removal rate evaluation; wheel characteristic investigation; and use of modulus-of-rupture bars for basic grindability studies.

MIRUC features state-of-the-art equipment for basic process research such a Sabre multi-axis grinder, a Weldon cylindrical grinder, a Harig surface grinder, a Cincinnati Milacron centerless grinder, a Nicco creep-feed grinder, and a Chand-Kare grindability tester. All instrumented equipment can record spindle vibration; spindle horsepower; acoustic emission; x, y, z forces; and other critical data via a Labview-based, data-collection interface.

Working with industry, MIRUC has developed a simple, effective method for calculating grinding ratios (the volume of workpiece material removed per unit volume of wheel wear). Since diamond grinding wheels are expensive, researchers need to know the grinding ratio before estimating the tooling cost of a production process. Other studies done with industry include developing cost-effective methods for grinding complex ceramic components; adapting an inexpensive multi-axis vertical machining center for ceramic grinding applications; evaluating newly-developed machinery and tools; creating a centerless grinding process; and optimizing grinding processes.

Micro-Metrology

Oak Ridge's Ultraprecision Manufacturing Technology Center has developed a unique capability for performing dimensional metrology of micro-fabricated components. This capability uses techniques such as stylus profilometry, modified video microscopy, and optical interferometry to accurately assess the dimensional variations within micro-fabricated structures.

The various micro-metrology techniques offer engineers a way to accurately measure the dimensions and dimensional variation of micro-fabricated components. Stylus profilometry offers dimensional measurements with better than 0.1-micrometer accuracy over a 250-micrometer range. Modified video microscopy has approximately 2-micrometer accuracy over a non-contact, 5-millimeter range. Optical interferometer has an accuracy of better than 0.1-micrometer for sizes greater than 1 millimeter.

New families of micro-manufactured components and systems will require unique micro-metrology techniques and tools for assuring the manufacturability of components. Micro-metrology techniques will offer engineers the opportunity to evaluate manufacturing processes by assessing specific production parts. During system development, micro-metrology tools will be invaluable for identifying dimensional tolerances and for manufacturing subsystem parts. Overall, micro-metrology will provide engineers with repeatable system assemblies and proper system performance.

Nickel-Aluminum Bronze Casting

ORCMT's Work-for-Others program extensively uses 1/4-scale, nickel-aluminum bronze cast components for testing. Currently, non-DOE vendors may take up to 26 weeks to sandcast a component before sending it to ORCMT for machining. These castings typically have incorrect or inconsistent dimensions; contain internal voids and porosity; or display defects during the machining process which require extensive rework. ORCMT has developed a nickel-aluminum bronze casting process which can create quick, practical, high-quality, 1/4-scale castings.

ORCMT's nickel-aluminum bronze casting process involves creating a solid-part model which is used to produce multiple piece molds; electronically modeling the casting process via ProCast and making any necessary modifications to the model; producing numerical control tapes for machining the mold; machining the graphite molds; and pouring the casting by using a graphite system in a vacuum. ORCMT has demonstrated its casting process on a 1/4-scale propeller blade and produced a reusable graphite mold. X-ray analysis verified that the finished cast contained no internal voids or porosity. In addition, the process eliminated or minimized dead parts, weld repairs, machining probes, setups, and inspections.

ORCMT will be working with the Navy on additional casting and inverse-heat-conduction studies in support of the New Attack Submarine propulsor development. These studies will include solidification studies of sub-scale components; solidification studies and riser/gating design of the complete propulsor; and experimental design and data reduction for defining monoblock casting heat-transfer coefficients.

Recycle Products Purchasing Plan

In 1992, President Clinton issued the Federal Acquisition, Recycling, and Waste Prevention Order which called for all federal organizations and contractors to increase the percentage of recycled product purchases. The EPA designated five categories of recycled products in RCRA, Section 6002: re-refined oil, retread tires, concrete with fly ash, recycled building insulation, and recycled paper products.

Between 1990 and 1995, Lockheed Martin Energy Systems (LMES) and Lockheed Martin Energy Research (LMER) showed a steady increase in recycled product purchases. Total purchases toward the EPA-designated categories in RCRA, Section 6002 rose from 6% to 38% as a result of several proactive initiatives. These initiatives included forming a three-site affirmative procurement team to coordinate affirmative procurement efforts; adding affirmative procurement criteria to proposals for paper, custodial products, and other Accelerated Vendor Inventory Delivery (AVID) agreements; offering recycled product alternatives for paper, custodial products, and tire AVID agreements; sponsoring recycled-product fairs for employees; and altering the language in engineering and procurement product specification documents which discouraged the use of recycled content material.

In addition, LMES and LMER cited examples for promoting the purchase of recycled products. Among these include making re-refined motor oil available to garages by inclusion in the lubricating oil AVID agreement; forming a three-site garage team to develop guidelines which removed the barriers for retread tire purchases; switching to a recycled content computer paper which was suitable for high speed printers; establishing an AVID agreement and tracking procedure for office products that contained multiple recycled products; negotiating the removal of virgin copier paper; using recycled content trash bags; and printing company business cards on recycled content card stock.

Silicone Rubber Fiber Optics

ORCMT has been using a new class of optical fibers called silicone rubber fiber optics (SRFO) in many sensor development programs. Fabricated from a silicone elastomer, SRFO features a remarkable elasticity (Figure 3-7). This elasticity allows SRFO to be tied into knots, stretched to twice its original length, or compressed from its normal circular profile into an ellipse. After enduring such deformations, SRFO sustains no permanent damage and will return to its original shape and size. Standard optical fibers use relatively inflexible materials such as glass or plastic which will usually break when stretched.

As expected, SRFO's transmission characteristics will vary whenever the fiber is subjected to moisture, elongation, compression, or displacement. This feature enables SRFO to be used for monitoring static and dynamic pressure, moisture, relative humidity, force, weight, strain, and other physical parameters. SRFO can also transmit more optical

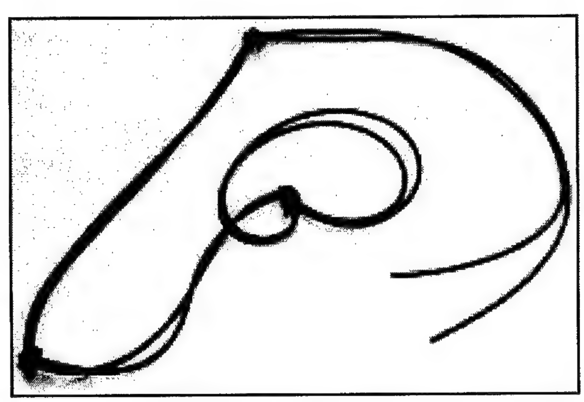


Figure 3-7. Section of Silicone Rubber

power than standard optical fibers which makes it ideal for systems that require small, rugged, and relatively inexpensive sensors.

ORCMT has been developing various SRFO sensing systems such as a portable weighing device for vehicles in motion, an on-line vehicle counter, a self-weighing trailer, and miniature pressure sensors. In some applications, the SRFO sensing systems consistently met or exceeded the reliability standards of conventional sensing systems, and are less prone to oscillatory ringing. Possible applications include embedding SRFO sensors into carpets for security systems; into concrete for measuring crack formation, strain, or curing; and into orthopedic devices for monitoring rehabilitation or sports training.

Thermal Spray Development

ORCMT's Thermal Spray Technology Center features experienced personnel, state-of-the-art facilities, and thermal spray equipment. Thermal spray capabilities provided by the Center range from corrosion coatings to near-net shape component development.

ORCMT has been investigating thermally-sprayed dielectric materials as coatings for electrostatic chucks for fixturing silicon wafers during high temperature (600°C) vacuum processing. Electrostatic chucks can reduce edge and front-side wafer effects; provide better temperature uniformity and control; improve wafer flatness; and reduce moving parts. ORCMT is developing B_4C as a thermally sprayed coating because of its low thermal expansion, valuable mechanical properties (high hardness, strength and modulus), high melting point, specific heat, and melting enthalpy. However, these advantageous properties also make B_4C difficult to apply as a thermal spray.

ORCMT has been investigating thermal spray applications such as beryllium coatings; free-standing and near-net shaped components; in-process control DXT (density x thickness); wear-resistant surfaces; and molten metals containment and processing. Potential applications include low-Z coatings for reactor components; dielectric coatings for tooling applications; protective coatings for containment and processing of molten materials; thermally-conductive coatings for injection molding tooling; wear-resistant coatings for military applications; corrosion-resistant coatings for high-temperature environments and fossil energy applications; and enhanced thermal spray process and materials development.

Traced Oralloy Casting Advisor

Precision casting requires an experienced operator with expert skills and knowledge. Typically passed from expert to apprentice employee, casting skills and knowledge are now being lost through downsizing. However, ORCMT is developing a Traced Oralloy Casting Advisor (TOCA) system which will preserve the skills and knowledge of top casting experts in the area of depleted uranium.

The TOCA system will also provide instructions for making uranium alloy castings with uniform loading of trace elements. Tracers (low-concentration, metal-element additions to uranium) are used for radiochemical diagnostic purposes after a test weapon event. The TOCA system will determine the material types, forms, and amounts; select the form for pouring the billet; specify the furnace type and temperature profile; and choose the quenching and cooling conditions. Additional instructions will provide the user with critical mold design dimensions, the best tracer alloying method, the appropriate charge mass, the required tracer mass, furnace capacity, and safety information.

ORCMT expects the TOCA system to reduce the time, cost, and training requirements associated with making accurate castings. Phase I will concentrate on capturing the casting knowledge and building it into a working, user-friendly system. Phase II will focus on identifying methods that will reduce costs, improve schedules, increase efficiency, and provide quick response times.

Facilities

Advanced Command Post Project

In 1989, Oak Ridge was tasked by the U.S. Army to define, develop, and deploy an effective and reliable communications system for the warfighting commands. Studies for the Advanced Command Post Project included large screen displays, terrain visualization, erectable antennae, and transportable shelters.

As a result, Oak Ridge established Advanced Command Post prototypes in 1991 to enhance and improve the lines of communication among the various warfighting and support commands. The prototypes consisted of quick-assembly, transportable shelters which housed various communication interfaces such as multi-point video teleconferenc-

ing, electronic mapboards, and a 36-inch map facsimile machine. In addition, the prototypes served as the primary command and control elements for the V Corps in its NATO Peacekeeping Implementation Force.

Advanced Machining Systems

Partnered with industry, academia, and professional organizations, ORCMT is developing advanced machining systems to increase productivity and serve as an evaluation platform for industry. This endeavor develops new manufacturing processes and evaluates state-of-the-art machine tools, components, and processes. Active projects include commodity machine tools, hexapod machine tools, advanced turning machines, and advanced machining processes.

The commodity machine tools project shows the feasibility of replacing transfer lines with a single machine. A milling machine in the ORCMT Skills Demonstration Center has been instrumented to monitor machine temperature, vibration, and cutting loads. Objectives of the project include investigating how the machine functions when operated near its maximum design capabilities; achieving a better understanding of noise characteristics; and detecting pending motor, gear, bearing, and slide failures. Success with these objectives could result in eliminating most transfer lines and provide an increase in reliability.

The hexapod machine tool project shows promise as an evaluation platform for industry. A Hexel stewart platform machine at ORCMT (capable of milling, precision drilling, and turning) features a five-axis capability over a 1.0-meter volume; a high stiffness; a water-cooled, hybrid-ceramic bearing spindle; a Windows 95 Pentium-based controller; and a small footprint. Objectives of the project include multiple operations from a single platform; high speed and thin wall machining; rapid prototyping; and contained metal removal operations when inert atmospheres are involved. The machine is currently being evaluated for accuracy and capability.

The endeavor of developing advanced machining systems may enable Oak Ridge to survive the production constraints predicted for the year 2000 and beyond. Strategies suggest that Oak Ridge will be able to produce any stockpiled component on short notice without up-front testing or failures.

Advanced Open Architecture Controls

Partnered with industry, academia, and professional organizations, ORCMT is developing advanced open architecture controls to improve competitive manufacturing operations. This endeavor develops, enhances, and evaluates advanced control systems and components for material removal, assembly, and dimensional inspection applications. Active projects include agile production operations, dimensional inspection machines, control of pneumatic positioning devices; and evaluation of open architecture controls.

For the dimensional inspection machines project, a Moore M32 measuring machine has been configured as a Y/Z/Theta inspection machine and retrofitted with an in-house designed intelligent inspection system. The in-house system consists of an open controller with commercially-available analysis software. Objectives of the project include porting the intelligent inspection system to a Windows NT computing platform, developing enhancements for coordinate measuring machine operations, and producing a Dual Y/Z/Theta inspection machine. The mechanisms could minimize training and maintenance costs while ensuring long-term usability.

For the pneumatic positioning devices project, ORCMT is developing advanced methodologies to control the velocity and the position of pneumatic devices. Using an in-house controls development system, ORCMT developed and simulated pneumatic control algorithms. Next, ORCMT evaluated these algorithms by connecting a pneumatic cylinder to the controls development system. Results indicate that the project has achieved a positioning accuracy that is almost one order of magnitude better than existing techniques. The mechanisms could replace hydraulic or electromechanical devices with cleaner, faster, and inexpensive pneumatics.

Open architecture controls represent an essential tool for integrating future technologies with present control strategies. The endeavor of developing advanced open architecture controls may enable Oak Ridge to survive the production constraints predicted for the year 2000 and beyond.

Energy Management

With an annual energy consumption of 5 million BTUs, Oak Ridge spends approximately $32 million per year on electricity, coal, and natural gas. To

oversee its energy costs and needs, Oak Ridge established an energy management team.

The energy management team consists of an energy manager for each site (the Y-12 Plant, the East Tennessee Technology Park, and ORNL) and ten energy management engineers. Through its expertise and coordination, the team has conducted energy and lighting studies; performed piping analyses to evaluate electrical and HVAC systems; analyzed building components; and developed specifications for retro-fit projects. Oak Ridge established training programs that include predictive and preventive maintenance techniques for the energy management staff. Oak Ridge also provides engineering services and technical support to government and industry organizations; assists manufacturers with applied research and development; and operates a testbed facility for analyzing air conditioning equipment, refrigeration equipment, electric motors, and pumps.

Oak Ridge has received numerous awards for its energy management efforts. Awards include DOE Defense Program's In-House Energy Management Award in 1994; the Federal Energy Management Program's Showcase Facility Award in 1995; and DOE's Renew America Award in 1996.

Energy Savings Performance Contracting

With an energy cost of $32 million per year, Oak Ridge established an energy management team to devise ways of reducing the facilities' energy requirements. Despite budget cuts, the team needed to find a way to implement capital-intensive, energy cost-saving improvements without incurring the up-front costs. In response, Oak Ridge has begun to implement the Energy Savings Performance Contracting (ESPC) method.

ESPC involves working with a contractor (typically, an energy service company) who designs, installs, and maintains the energy cost-saving measures for a facility. As payment, the contractor receives a share of the facility's energy cost savings. Most ESPCs incorporate a savings guarantee, wherein the contractor ensures that the facility will receive a certain level of energy cost savings regardless of the actual performance of the energy-saving measures. If the energy-saving measures do not meet the initial estimates, then the contractor receives a reduced payment for its services. In some situations, the difference between the actual and estimated savings must also be paid by the contractor to the facility.

Oak Ridge developed its first comprehensive ESPC with the Federal Energy Management Program. After receiving ESPC training from the program, the energy management team gathered information from meetings with five energy service companies. Next, the team briefed the energy manager at each Oak Ridge site (the Y-12 Plant, the East Tennessee Technology Park, and ORNL) to obtain support and approval for the proposed ESPC. Oak Ridge is currently in the implementation stages of this ESPC.

Facility Design Services

ORNL's Facility Engineering Group provides complete engineering, scientific, and manufacturing support to DOE facilities: three in Oak Ridge (the Y-12 Plant, the East Tennessee Technology Park, and ORNL), one in Portsmouth, Ohio, and one in Paducah, Kentucky. Capabilities provided by the Facility Engineering Group include design and analysis; systems engineering; construction; and project management.

Design and analysis capabilities include finite element; vibration; pipe stress; telerobotics; gloveboxes; vacuum systems; cryogenics; magnetics; nuclear technologies; and facility infrastructure design. Systems engineering capabilities include mission analysis; requirements management; systems integration and control; and economic, value and risk analyses. Construction support capabilities include planning; field support; facility start-up; and management support functions. Project management support capabilities include planning; procurement; subcontracts; scope; cost; and schedule management.

ORNL's Facility Engineering Group offers state-of-the-art facilities with experienced personnel. The Group can also provide assistance in specialized technical services such as manufacturing technology, chemical processes, welding, natural phenomena engineering, geological, hydrologic, hydraulic, environmental, and waste management.

Microwave Interrogation

Oak Ridge has proposed a microwave-based method for detecting drivetrain component wear (in-service) by interrogating oil morphology. The optimal system would recognize ferrous and non-ferrous particles,

and indicate size and distribution. Tasks for the system's development would include identifying cavity design for maximum sensitivity; prioritizing potential target particles; identifying useful transmission frequency range; developing conditioning and discrimination circuitry; performing tests and calibrations; evaluating data; and reporting results.

Microwave signals, produced by a 12- to 24-volt DC battery, travel through an optimally-geometric enclosure and interact with particles in the oil stream that pass through the cavity. A receiver, positioned at the opposite end of the cavity, can detect changes in the microwave signals. Carbon, metal, and organic metal particles can also be detected at a level of 10 parts per million via the proper collection, processing, and discrimination of the altered signal. However, this method is limited to the size and distribution of the particles, and may be incapable of discriminating between different materials.

Oak Ridge's microwave interrogation concept has completed a feasibility study. If fully developed, the concept could provide accurate, on-site analyses of oil morphology, and may increase the accuracy of predictive maintenance techniques for determining the condition of equipment. Quicker, more accurate information would help to extend equipment durability, improve productivity, and reduce maintenance costs.

Peak Torsional Strain Monitor

Condition-based maintenance offers a less costly, but more challenging methodology than traditional corrective and preventative maintenance practices. Typically, rotating equipment condition assessment relies on multiple sensor vibration analysis. To complement this analysis, ORCMT has proposed a non-contact, strain-sensing element for peak torsional strain monitoring.

Typical techniques of rotating condition assessment include vibration, thermographic, and oil analyses. In most predictive maintenance programs, these techniques are not implemented continuously, but rather on a weekly or monthly sampling schedule. Although sample monitoring can reduce maintenance costs, continuous monitoring can more efficiently record the true usage levels of equipment and detect problems associated with peak loading.

ORCMT has successfully completed an initial feasibility study for a transformation-induced plasticity (TRIP) steel sensor to measure peak strain (Figure 3-8). The special crystal structure of the steel material responds to peak strains by changing from paramagnetic to ferromagnetic, and possesses memory to indicate the maximum value of the strain. In rotating machinery, slip rings transfer signal transmissions from moving to stationary parts. However, slip rings have industry-wide reliability and data fidelity problems. TRIP sensors use

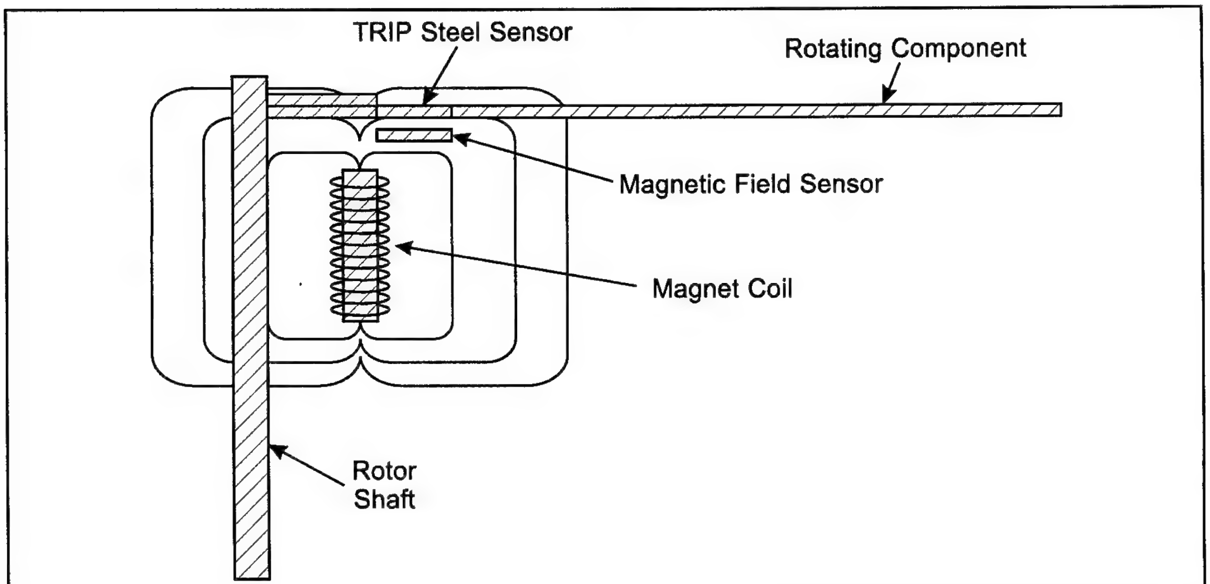


Figure 3-8. Transformation-Induced Plasticity Steel Sensor

magnetic field detection (inherently non-contact) which makes them attractive for maximum torque measurements in rotary applications.

TRIP sensing has been successfully demonstrated for bridges, mining applications, and airframes. Possible benefits of this novel technique include improved condition-based maintenance monitoring and the ability to record peak torque histories for operational machinery.

Predictive Maintenance

In conjunction with a CRADA program, Oak Ridge is developing a predictive maintenance system for predicting machine tool maintenance needs and performance degradation during operation. The system will allow staff to schedule maintenance service at convenient times and reduce productivity losses associated with unexpected machine failures.

The predictive maintenance system uses sensors such as accelerometers, electrical current sensors, thermocouples, resistive temperature detectors, and pressure transducers to gather data from the machine tools during operations. The system uses LabView data acquisition software, standard signal processing algorithms, and electrical signature analysis to collect and analyze real-time data. By collecting and analyzing sensor data in real-time, the system can predict degradation trends and eliminate run-to-failure and time-directed maintenance methods.

Oak Ridge has assembled the predictive maintenance system and developed the graphical user interface needed for displaying the recorded parameters. The next task involves running a battery of tests. If Phase I is successful, the methodology and algorithms behind this system will be considered for integration into the machine tool controller. Possible benefits of predictive diagnostics include increasing machine availability and decreasing maintenance costs.

Wireless Technology

Wireless technology has already revolutionized the communication systems for business, personal, and recreational use. The next stage of wireless systems involves using sensors and actuators to improve manufacturing process control and impact predictive maintenance data acquisition. ORCMT is investigating methods to transmit distributed sensor data through wireless networks.

Predictive diagnostics rely on traditional sensors such as accelerometers and thermocouples or thermography. Typically, either a technician gathers data from sensors throughout the facility on a scheduled basis, or a central collection computer records data which is transmitted across wires from each sensor. The former method may miss failures because of infrequent sampling intervals, while the latter requires high initial costs for wiring each sensor. Wiring a facility can run from $40 per foot of wire for a chemical plant to $2,000 per foot of wire for a nuclear power plant.

Wireless systems already use radio-frequency tags on components and machinery to automatically track inventory and notify subsystems throughout a manufacturing operation. In addition, new developments in spread-spectrum radio frequency technology have eliminated earlier problems (interference, multi-path, and line-of-sight constraints) commonly associated with narrow-band FM devices. Spread-spectrum radio frequency technology now offers direct sequencing, frequency hopping, and high immunity to interference by using a high bandwidth (2 megabits per second) and built-in encryption.

Power scavenging, access control, and high initial costs still present challenges to wireless systems. However, ORCMT has successfully developed and demonstrated wireless systems in some research projects, such as microwave telemetry for sensors in hazardous environments; wireless controls for the Athens Utility Board; and a fully-integrated, self-powered microcircuit which was glued to a bee to monitor its location for the Department of Agriculture.

Wireless technology provides several benefits over traditional methods for condition monitoring and process control. Benefits include flexibility, remote accessibility, and increased electrical reliability. Possible long-term advantages are reduced operational costs and increased system availability.

Logistics

Automated Container Identification System

Oak Ridge has developed an automated container identification system, SmartShelf™, which monitors the inventory in an active storage area. As an inexpensive method, SmartShelf™ automatically maintains surveillance of the containers; documents

any container movements by time, date, and personnel; and denies access to unauthorized personnel into the storage area.

Using a standard modular telephone wire and jacks, SmartShelf™ connects an electronic identifier from a container to a controller. The controller uses firmware to detect the additions or removals of containers, recognizes alarm conditions, performs self-testing, and communicates the data to a host computer via an RS-485 serial communication line. With a maximum of 128 electronic identifiers connected to a controller and a maximum of 32 controllers connected via a single RS-485 line, a single host computer can track 4,096 containers.

Oak Ridge's current inventory system requires a two-person inspection team to enter the storage area. The team uses portable barcode readers to scan labels, identify containers, and gather data for loading onto a local personal computer. SmartShelf™ will improve inventory accuracy, eliminate manual searches, allow 100% inventory of stored material instead of random sampling, reduce labor costs, decrease inventory time, and eliminate radiation exposure to personnel. The cost per container is less than $10.

Continuous Automated Vault Inspection System

Special nuclear [radioactive] material (SNM) must periodically be inventoried to meet DOE accountability program requirements. Oak Ridge has developed a continuous automated vault inspection system (CAVIS) to minimize the labor, time, and radiation-exposure aspects associated with SNM inventories.

Traditionally, SNM inventories require a (minimum) four-person inspection team to enter the storage area in accordance with safety regulations. Any automated security systems that need to be temporarily disabled during the inventory have to be replaced with armed guards. With the high cost of performing such a task ($200 per item), inventories typically are done only on a sampling basis. However, accidental or actual triggering of an alarm requires emergency inventories to be performed which results in shutting down all plant operations.

CAVIS works as a virtually-passive sensor system that can continuously monitor physical attributes from stored nuclear material. By using fiber optic and solid state sensors, CAVIS can verify item weight, temperature, gamma flux, relative enrichment, neutron flux (plutonium), location, and motion. Any changes in these attributes provoke an immediate response to the appropriate alarm system(s).

Currently, Oak Ridge has been field-testing two CAVIS systems. CAVIS offers a quick (100%) inventory method; shows potential for adapting to various storage configurations; and meets or exceeds all current DOE requirements for inventoried SNMs. Oak Ridge estimates that CAVIS will reduce monitoring costs by $180 thousand to $7.2 million for its three SNM vaults located at the Y-12 Plant.

Joint Flow and Analysis System for Transportation

In 1989, Oak Ridge developed the Joint Flow and Analysis System for Transportation (JFAST) as a multi-modal transportation analysis model for the U.S. Transportation Command and the Joint Planning Community. JFAST performs fort-to-foxhole modeling of military deployments on an international level.

JFAST can estimate transportation requirements, perform course-of-action analyses, and project delivery profiles of troops and equipment by air, land, and sea. Operated from a user-friendly, interactive screen, JFAST displays every country in the world with an overlay of various transportation modes such as highways, railroads, airline routes, and waterways. Features include instantaneous appearance of highways when prompted; automatic generation of Microsoft Word documents with text and graphics; and automatic linking of existing transportation information with Excel data to produce a PowerPoint presentation.

JFAST has been distributed to forty-two military command centers and planning organizations worldwide. JFAST was used for the military operations of Desert Shield and Desert Storm and the humanitarian efforts of Rwanda and Somalia. With unlimited applications, JFAST could control freight shipment scheduling and tracking; hospital pharmaceutical tracking; manufacturing planning simulation; and transportation control. Benefits include near real-time capabilities, minimal learning curve requirements, cost effectiveness, and commercial-off-the-shelf software usage.

Optical Time Domain Reflectometry-Based Active Seal System

Containers that store nuclear material must periodically be examined to ensure that their seals (tamper indicating devices) have not been broken. Traditionally, seal inspections require a two-person team to enter the storage area and physically examine the containers for evidence of tampering. Oak Ridge has developed an optical time domain reflectometry (OTDR)-based active seal system to minimize the labor, time, and radiation-exposure aspects associated with seal inspections.

The OTDR-based active seal system works as an active sensor system that can continuously monitor the seals on the stored containers. The system uses reusable fiber optic connectors (as seals), an OTDR, an optical fiber multiplexer, and a control computer. Fiber optics are linearly setup throughout a storage area and in contact with each inventoried container. Using a laser (positioned in two, opposite directions), the system can pinpoint a container's location within the storage area if a seal break occurs. In addition, the system will record the time of the breach.

Oak Ridge's OTDR-based active seal system can monitor containers up to several kilometers away and is compatible with various indoor and outdoor storage configurations. The system operates on a significantly lower per-item cost than other active seal technologies and can be fully automated with minimal maintenance requirements. In addition, the OTDR-based active seal system will eliminate physical inspections, provide continuous monitoring capability, reduce labor costs, and eliminate radiation exposure of personnel.

Management

Engineers and the Shop Floor Course

The Manufacturing Skills Campus offers advanced manufacturing training in precision machining and industrial technologies. Instructors consist of senior craft workers with an average of 20 years of experience in advanced manufacturing production operations. Of all the courses offered by the Skills Campus, the Engineers and the Shop Floor course provides one of the most unique training opportunities.

The Engineers and the Shop Floor course provides engineers and managers with hands-on experience in an advanced manufacturing shop floor environment. This unique perspective allows participants to enhance their process knowledge base and manufacturing capabilities. The course emphasizes theory, application, and interaction with shop floor personnel. Designed in a modular format, the course can be customized to a participant's needs in manufacturing and engineering systems; process and fabrication; and advanced industrial practices. Participants gain experience in machine tool operation; tooling and fixturing requirements; inspection techniques; and flexible manufacturing practices.

Intelligent Advisors

In the 1980s, Oak Ridge conducted a study that identified 110 highly-skilled key individuals who were approaching retirement age. As a result, Oak Ridge began examining intelligent advisor systems as a means to capture and preserve the knowledge and skills of its experts. These systems rely on the integration of models, executable data, and graphics; a software development environment; and a knowledge architecture.

To develop an intelligent advisor system, Oak Ridge first gathered knowledge from experienced personnel through interviews. Next, an electronic paradigm was created using information, models, and analysis tools to reflect the relevant context of experience and rationale for decision-making. All of Oak Ridge's intelligent advisor systems include four basic elements: capturing process and expert knowledge; linking graphics, computer aided design, and product definitions; integrating nongraphic data; and seamlessly integrating models, information, and data into an easy-to-use man-machine interface.

Intelligent advisor systems integrate design expertise, methods, and models which allow users to determine a project's manufacturability early in the design cycle. In addition, these systems can decrease turnaround time, reduce labor costs, and ensure the inclusion of concurrent engineering principles and optimum production planning.

Law Enforcement Computer System

In June 1996, ORCMT reviewed the Tennessee Corrections Department's computer system for processing criminal information history. The state's current database lacked easy accessibility; offered limited data and query capabilities; and processed requests slowly. In response, ORCMT has devel-

oped an electronic management system for compiling, retrieving, processing, storing, and tracking information on convicted criminals throughout the State of Tennessee.

National statistics show that 5% of the population commits 80% of the crimes and of these criminals, 70% will be repeat offenders. Therefore, statistics on habitual criminals provide valuable information to police officers, investigators, and prosecuting attorneys. By working with the Tennessee Department of Corrections and Knox County, LMER's Data Systems Research and Development extracted a state file with the necessary data elements for designing Data Share. This PC-based system uses Microsoft Access and provides users with the ability to query the database by name, social security number, FBI number, state identification number, physical characteristics, individual status, and type of offense. The system can be accessed by either a desktop personal computer or a laptop.

Since completing a working model, ORCMT has been extracting and compiling the remaining 140,000 files stored in the state's database. The system will provide law enforcement officials with a quick and easy-to-use resource for solving crimes. In addition, ORCMT has been constructing an Internet version of its system, and future plans include developing software which can generate statistics and trends.

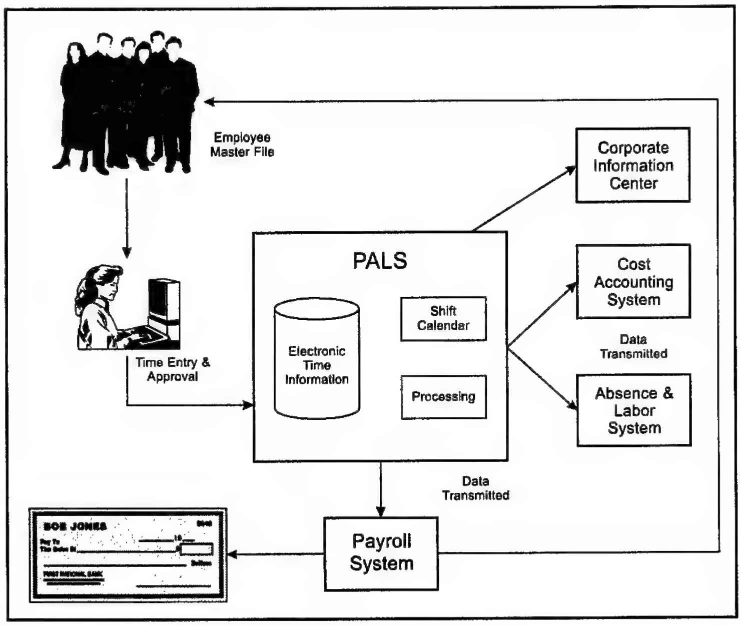


Figure 3-9. Data/System Interactions

Payroll, Absence, and Labor System

Prior to January 1996, Oak Ridge used traditional payroll methods that relied on a payroll time card system with 43,000 time cards per month, 10 internal systems, 660 time card racks, 23 timekeepers, eight data entry operators, and one optical character scanner to serve approximately 16,000 employees. Each week, timekeepers manually processed 8,000 cards for the hourly and weekly employees on an individual basis and verified the data through guidelines such as union contracts, policies, procedures, and regulations. In addition, eight electronic collection systems collected effort data on a weekly basis.

Oak Ridge developed the Payroll, Absence, and Labor System (PALS) to consolidate its electronic collection systems, eliminate time cards, and provide a user-friendly interface for the user. PALS (Figure 3-9) is a multi-platform client/server application that provides the user with an open architecture. Features include a graphical user interface; self input, group input, and approver user roles; multiple approval level support; time-in and time-out information defaults based on shift assignment; complete audit trail views for time entry and approval activity; posting of effort charges as daily or weekly totals; automated closure of time records; and interfaces to other systems such as payroll, absence tracking, labor distribution, and cost accounting.

Oak Ridge installed and developed PALS in two years at a cost of $4 million. Since installation, PALS has reduced internal systems from 11 to 1; full-time (equivalent) personnel from 27 to 12; and individual efficiency gains from 22 minutes to less than 6 minutes. Oak Ridge estimates its total savings from PALS at $3 million per year.

Preventive Optimization Program

ORCMT has developed a Preventive Optimization Program (POP) which maintains essential structures, systems, and components (ESSCs) by using a Reliability Centered Maintenance philosophy. As an effective equipment reliability program, POP analyzes failure modes, uses performance indicators, and identifies the primary characteristics of ESSCs for the safe operation of a facility.

ORCMT built the concept of POP around the integration of three major computer systems (the facilities' database; the condition assessment survey; and the maintenance scheduling and planning software) to create an easy-to-use, homepage-based system. Via a point-and-click method, POP allows the user to search throughout the layers of a facility including total plant layout, individual building layout, system distribution diagrams, and individual component information. POP implementation required identifying components by unique component numbers; determining essential and non-essential components and structures; identifying maintenance requirements and failure rates; developing standard operating procedures, predictive maintenance techniques, and a spare parts inventory; tracking the benefits of the program from reductions in maintenance costs to increases in unit availability; and developing a monitoring system that uses constant feedback for continuous improvement.

Since developing the prototype, ORCMT has begun implementing POP in its facilities maintenance systems. For two of the systems analyzed, POP implementation will provide a $262-thousand-per-year savings in maintenance labor and material costs. In addition, POP will redirect the maintenance program for the utilities and steam plant systems from 80% corrective maintenance and 20% preventive maintenance at startup to 25% corrective maintenance and 75% preventive maintenance at full implementation. Other benefits from POP include reduced labor hours; increased system reliability; optimized maintenance and operational work forces; specific vendor documentation for each system; and a consistent master equipment list.

Procurement Re-engineering

By applying re-engineering techniques, ORNL has simplified its procurement processes with positive results. The Procurement Department focused on five re-engineering initiatives: leadership and planning; information analysis and business results; human resources development and management; customer focus; and process management.

The Procurement Department has established 15 process teams which evaluate, compare, and improve departmental operations such as contract format, negotiations, and management; risk versus opportunity assessments; alternative dispute resolution; electronic commerce; and professional training programs. Evaluations are based on operational performance; internal/external customer requirements and feedback; industry benchmarking; and criteria from the Malcolm Baldrige Award. In addition, the teams identify champion departments in various tasks such as benchmarking, consolidation, supplier outreach, and training. Each team reports its progress to the departmental leadership group on a monthly basis.

As a result of procurement re-engineering, ORNL has streamlined its processes, increased productivity and efficiency; decreased costs; and reduced cycle times. The Procurement Department has reduced its workforce by 50 Full Time Equivalent; decreased cycle time by 18%; and increased customer satisfaction by more than 13%.

Appendix A
Table of Acronyms

Acronym	Definition
ADD	Analytical Development Department
AEMS	Air Emission Management System
ANS	Advanced Neutron Source
AOP	Advanced Oxidation Process
APTC	Advanced Propulsion Technology Center
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers
ASO	Analytical Services Organization
ATP	Adenosine Triphosphate
AVID	Accelerated Vendor Inventory Delivery
CAAA	Clean Air Act Amendments
CAVIS	Continuous Automated Vault Inspection System
CEC	Concurrent Engineering Center
CFC	Chlorofluorocarbon
CGH	Computer Generated Hologram
COLLAB	Collaborative Computing
COTS	Commercial-Off-The-Shelf
CRADA	Cooperative Research And Development Agreement
CREW	Controls Research Engineering Workbench
CSIS	Community-wide Secure Information Sharing
DOD	Department of Defense
DOE	Department of Energy
DNA	Deoxyribonucleic Acid
DNF	Differential Normalized Fluorescence
DNFSB	Defense Nuclear Facility Safety Board
DRIFT	Diffuse Reflectance Infrared Fourier Transform
DSRD	Data Systems Research and Development
EB	Electron-Beam
EMMIS-SW	Environmental Monitoring Management Information System for Surface Water
ER	Environmental Restoration
ESA	Electrical Signature Analysis
ESLIMS	Energy Systems Laboratory Information Management System
ESPC	Energy Savings Performance Contracting
ESSC	Essential Structures, Systems, and Components
GC/MS	Gas Chromatograph/Mass Spectrometer
GIS	Geographical Information System
GSA	General Services Administration

Acronym	Definition
HETS	Head End Treatment System
HIIT	Healthcare Information Infrastructure Technology
HITECC	Healthcare Information Technology Enabling Community Care
HOST	Healthcare Open Systems and Trials
HTDA	Hydroforming Tool-Die Design Advisory
HTML	High Temperature Materials Laboratory
IAQ	Indoor Air Quality
IAS	Information and Advisory System
ICEPAC	Individual Controlled Environment for Pulsed Addition and Crystallization
IMF	Integrated Multi-media Functionality
IMPET96	Induction Motor Performance Evaluation Tool 96
IR	Infrared
ISMV	Image Science and Machine Vision
JFAST	Joint Flow and Analysis System for Transportation
LARES	Laser Ablation from Rapidly Exchanged Sources
LIF	Laser-Induced Fluorescence
LMER	Lockheed Martin Energy Research
LMES	Lockheed Martin Energy Systems
MFC	Mass Flow Controller
MFDL	Mass Flow Development Laboratory
MIRUC	Machining and Inspection Research User Center
MOST	Manufacturing Opportunities through Science and Technology
MOV	Motor Operated Valve
MPM	Mechanical Properties Microprobe
NGM	Next Generation Manufacturing
NIST	National Institute of Standards and Technology
ORCMT	Oak Ridge Centers for Manufacturing Technology
ORMEL	Oak Ridge Motor Efficiency and Load
ORNL	Oak Ridge National Laboratory
OTDR	Optical Time Domain Reflectometry
PALS	Payroll, Absence, and Labor System
PEMS	Project Environmental Measurements System
PLD	Pulsed Laser Deposition
POP	Preventive Optimization Program
RCRA	Resource Conservation and Recovery Act
RSV	Resupply Vehicle

Acronym	Definition
SNM	Special Nuclear Material
SPH	Self-Propelled Howitzer
SPME	Solid Phase Membrane Extraction
SRFO	Silicone Rubber Fiber Optics
SSA	Spatial Signature Analysis
TAP	Technical Assistance Program
TEAM	Technologies Enabling Agile Manufacturing
TIS	Travel Information System
TOCA	Traced Oralloy Casting Advisor
TRIP	Transformation-Induced Plasticity
UMAT	Ultrasonic Material Acoustic Testing
VDI	Vector Displacement Interferometer
WFO	Work-for-Others

Appendix B

BMP Survey Team

Team Member	Activity	Function
Larry Robertson (812) 854-5336	**Crane Division** **Naval Surface Warfare Center** Crane, IN	**Team Chairman**
Adrienne Gould (703) 696-8485	**Office of Naval Research** Arlington, VA	**Technical Writer**
Amy Scanlan (301) 403-8100	**BMP Center of Excellence** College Park, MD	**Technical Writer**
Cheri Spencer (301) 403-8100	**BMP Center of Excellence** College Park, MD	**Technical Writer**

Design Team

Team Member	Activity	Function
Ron Cox (812) 854-5251	**Naval Surface Warfare Center** Crane, IN	**Team Leader**
Brian Anderson (513) 255-2363	**Wright-Patterson Air Force Base** Dayton, OH	
Ann Elsen (301) 405-0221	**University of Maryland** College Park, MD	
Duane Maddock (909) 273-4617	**Naval Warfare Assessment Division** Corona, CA	

Production Team 1

Team Member	Activity	Function
Bob Jenkins (703) 602-3003	**Naval Sea Systems Command** Arlington, VA	**Team Leader**
Charles Antinone, Jr. (304) 797-2528	**Weirton Steel Corporation** Weirton, WV	
Carl Byington (814) 865-7060	**Penn State University** State College, PA	
Jean Millick (703) 271-9055	**Production Technology, Inc.** Arlington, VA	

Production Team 2

Don Hill (317) 306-3781	**Naval Air Warfare Center** Indianapolis, IN	**Team Leader**
Anne Marie SuPrise (301) 403-8100	**BMP Center of Excellence** College Park, MD	
Ron Hawkins (301) 405-3814	**University of Maryland** College Park, MD	

Production Team 3

Nick Keller (812) 854-5331	**Naval Surface Warfare Center** Crane, IN	**Team Leader**
Mark Barclay (908) 323-1182	**Naval Air Warfare Center** Lakehurst, NJ	
Jennifer Koury (703) 696-0344	**Office of Naval Research** Arlington, VA	

Environment Team

Kip Hoffer (812) 854-6446	**Naval Surface Warfare Center** Crane, IN	**Team Leader**
Darrel Brothersen (319) 295-3768	**Rockwell Collins Avionics and Communications** Cedar Rapids, IA	
Beth Cook (205) 544-2545	**NASA Marshall Space Flight Center** Huntsville, AL	

Management Team

Rick Purcell (301) 403-8100	**BMP Center of Excellence** College Park, MD	**Team Leader**
Larry Halbig (317) 306-3838	**Naval Air Warfare Center** Indianapolis, IN	
Dick Rumpf (703) 351-5080	**Rumpf Associates International** Arlington, VA	

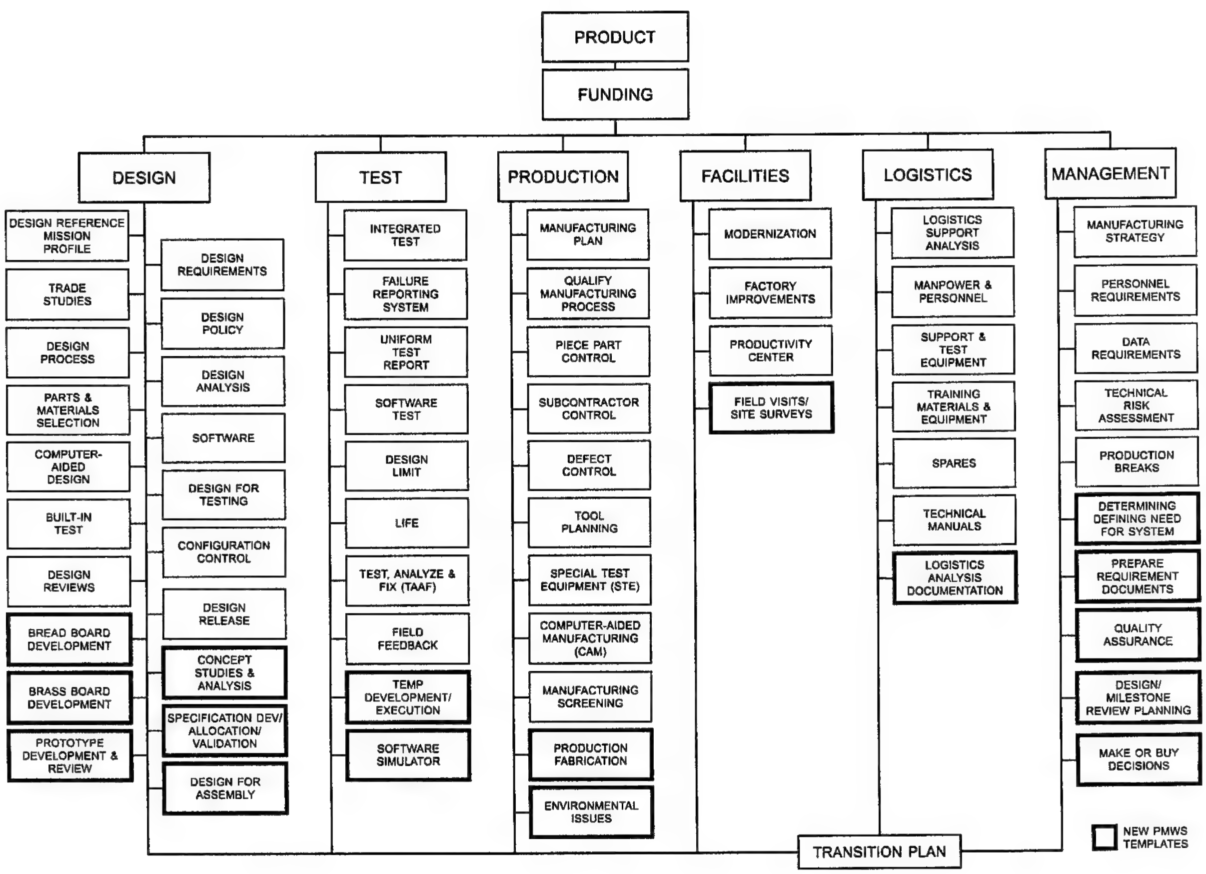
Appendix C

Critical Path Templates and BMP Templates

This survey was structured around and concentrated on the functional areas of design, test, production, facilities, logistics, and management as presented in the Department of Defense 4245.7-M, *Transition from Development to Production* document. This publication defines the proper tools—or templates—that constitute the critical path for a successful material acquisition program. It describes techniques for improving the acquisition process by addressing it as an *industrial* process that focuses on the product's design, test, and production phases which are interrelated and interdependent disciplines.

The BMP program has continued to build on this knowledge base by developing 17 new templates that complement the existing DOD 4245.7-M templates. These BMP templates address new or emerging technologies and processes.

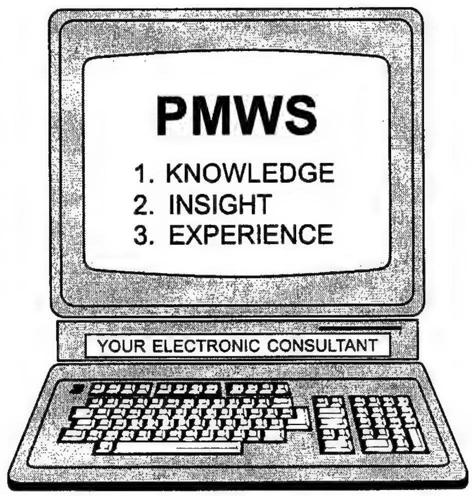
"CRITICAL PATH TEMPLATES FOR TRANSITION FROM DEVELOPMENT TO PRODUCTION"



Appendix D

BMPnet and the Program Manager's WorkStation

The BMPnet, located at the Best Manufacturing Practices Center of Excellence (BMPCOE) in College Park, Maryland, supports several communication features. These features include the Program Manager's WorkStation (**PMWS**), electronic mail and file transfer capabilities, as well as access to Special Interest Groups (SIGs) for specific topic information and communication. The BMPnet can be accessed through the World Wide Web (at http://www.bmpcoe.org), through free software that connects directly over the Internet or through a modem. The PMWS software is also available on CD-ROM.



PMWS provides users with timely acquisition and engineering information through a series of interrelated software environments and knowledge-based packages. The main components of PMWS are KnowHow, SpecRite, the Technical Risk Identification and Mitigation System (TRIMS), and the BMP Database.

KnowHow is an intelligent, automated program that provides rapid access to information through an intelligent search capability. Information currently available in KnowHow handbooks includes Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), MIL-STD-2167/2168 and the DoD 5000 series documents. KnowHow cuts document search time by 95%, providing critical, user-specific information in under three minutes.

SpecRite is a performance specification generator based on expert knowledge from all uniformed services. This program guides acquisition personnel in creating specifications for their requirements, and is structured for the build/approval process. SpecRite's knowledge-based guidance and assistance structure is modular, flexible, and provides output in MIL-STD 961D format in the form of editable WordPerfect® files.

TRIMS, based on DoD 4245.7-M (the transition templates), NAVSO P-6071, and DoD 5000 event-oriented acquisition, helps the user identify and rank a program's high-risk areas. By helping the user conduct a full range of risk assessments throughout the acquisition process, TRIMS highlights areas where corrective action can be initiated before risks develop into problems. It also helps users track key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities.

The **BMP Database** contains proven best practices from industry, government, and the academic communities. These best practices are in the areas of design, test, production, facilities, management, and logistics. Each practice has been observed, verified, and documented by a team of government experts during BMP surveys.

Access to the BMPnet through dial-in or on Internet requires a special modem program. This program can be obtained by calling the BMPnet Help Desk at (301) 403-8179 or it can be downloaded from the World Wide Web at http://www.bmpcoe.org. To receive a user/e-mail account on the BMPnet, send a request to helpdesk@bmpcoe.org.

Appendix E

Best Manufacturing Practices Satellite Centers

There are currently six Best Manufacturing Practices (BMP) satellite centers that provide representation for and awareness of the BMP program to regional industry, government and academic institutions. The centers also promote the use of BMP with regional Manufacturing Technology Centers. Regional manufacturers can take advantage of the BMP satellite centers to help resolve problems, as the centers host informative, one-day regional workshops that focus on specific technical issues.

Center representatives also conduct BMP lectures at regional colleges and universities; maintain lists of experts who are potential survey team members; provide team member training; identify regional experts for inclusion in the BMPnet SIG e-mail; and train regional personnel in the use of BMP resources such as the BMPnet.

The six BMP satellite centers include:

<u>**California**</u>

Chris Matzke
BMP Satellite Center Manager
Naval Warfare Assessment Division
Code QA-21, P.O. Box 5000
Corona, CA 91718-5000
(909) 273-4992
FAX: (909) 273-4123
cmatzke@bmpcoe.org

Jack Tamargo
BMP Satellite Center Manager
257 Cottonwood Drive
Vallejo, CA 94591
(707) 642-4267
FAX: (707) 642-4267
jtamargo@bmpcoe.org

<u>**District of Columbia**</u>

Margaret Cahill
BMP Satellite Center Manager
U.S. Department of Commerce
14th Street & Constitution Avenue, NW
Room 3876 BXA
Washington, DC 20230
(202) 482-8226/3795
FAX: (202) 482-5650
mcahill@bxa.doc.gov

<u>**Illinois**</u>

Thomas Clark
BMP Satellite Center Manager
Rock Valley College
3301 North Mulford Road
Rockford, IL 61114
(815) 654-5515
FAX: (815) 654-4459
adme3tc@rvcux1.rvc.cc.il.us

<u>**Pennsylvania**</u>

Sherrie Snyder
BMP Satellite Center Manager
MANTEC, Inc.
P.O. Box 5046
York, PA 17405
(717) 843-5054, ext. 225
FAX: (717) 854-0087
snyderss@mantec.org

<u>**Tennessee**</u>

Tammy Graham
BMP Satellite Center Manager
Lockheed Martin Energy Systems
P.O. Box 2009, Bldg. 9737
M/S 8091
Oak Ridge, TN 37831-8091
(423) 576-5532
FAX: (423) 574-2000
tgraham@bmpcoe.org

Appendix F
Navy Manufacturing Technology Centers of Excellence

The Navy Manufacturing Sciences and Technology Program established the following Centers of Excellence (COEs) to provide focal points for the development and technology transfer of new manufacturing processes and equipment in a cooperative environment with industry, academia, and Navy centers and laboratories. These COEs are consortium-structured for industry, academia, and government involvement in developing and implementing technologies. Each COE has a designated point of contact listed below with the individual COE information.

Best Manufacturing Practices Center of Excellence

The Best Manufacturing Practices Center of Excellence (BMPCOE) provides a national resource to identify and promote exemplary manufacturing and business practices and to disseminate this information to the U.S. Industrial Base. The BMPCOE was established by the Navy's BMP program, Department of Commerce's National Institute of Standards and Technology, and the University of Maryland at College Park, Maryland. The BMPCOE improves the use of existing technology, promotes the introduction of improved technologies, and provides non-competitive means to address common problems, and has become a significant factor in countering foreign competition.

Point of Contact:
Mr. Ernie Renner
Best Manufacturing Practices Center of Excellence
4321 Hartwick Road
Suite 400
College Park, MD 20740
(301) 403-8100
FAX: (301) 403-8180
ernie@bmpcoe.org

Center of Excellence for Composites Manufacturing Technology

The Center of Excellence for Composites Manufacturing Technology (CECMT) provides a national resource for the development and dissemination of composites manufacturing technology to defense contractors and subcontractors. The CECMT is managed by the GreatLakes Composites Consortium and represents a collaborative effort among industry, academia, and government to develop, evaluate, demonstrate, and test composites manufacturing technologies. The technical work is problem-driven to reflect current and future Navy needs in the composites industrial community.

Point of Contact:
Dr. Roger Fountain
Center of Excellence for Composites Manufacturing Technology
103 Trade Zone Drive
Suite 26C
West Columbia, SC 29170
(803) 822-3705
FAX: (803) 822-3730
rfglcc@glcc.org

Electronics Manufacturing Productivity Facility

The Electronics Manufacturing Productivity Facility (EMPF) identifies, develops, and transfers innovative electronics manufacturing processes to domestic firms in support of the manufacture of affordable military systems. The EMPF operates as a consortium comprised of industry, university, and government participants, led by the American Competitiveness Institute under a CRADA with the Navy.

Point of Contact:
Mr. Alan Criswell
Electronics Manufacturing Productivity Facility
Plymouth Executive Campus
Bldg 630, Suite 100
630 West Germantown Pike
Plymouth Meeting, PA 19462
(610) 832-8800
FAX: (610) 832-8810
http://www.engriupui.edu/empf/

National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology (NCEMT) provides a national center for the development, dissemination, and implementation of advanced technologies for metalworking products and processes. The NCEMT, operated by Concurrent Technologies Corporation, helps the Navy and defense contractors improve

manufacturing productivity and part reliability through development, deployment, training, and education for advanced metalworking technologies.

Point of Contact:
Mr. Richard Henry
National Center for Excellence in Metalworking Technology
1450 Scalp Avenue
Johnstown, PA 15904-3374
(814) 269-2532
FAX: (814) 269-2799
henry@ctc.com

Navy Joining Center

The Navy Joining Center (NJC) is operated by the Edison Welding Institute and provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities. The NJC works with the Navy to determine and evaluate joining technology requirements and conduct technology development and deployment projects to address these issues.

Point of Contact:
Mr. David P. Edmonds
Navy Joining Center
1100 Kinnear Road
Columbus, OH 43212-1161
(614) 487-5825
FAX: (614) 486-9528
dave_edmonds@ewi.org

Energetics Manufacturing Technology Center

The Energetics Manufacturing Technology Center (EMTC) addresses unique manufacturing processes and problems of the energetics industrial base to ensure the availability of affordable, quality energetics. The focus of the EMTC is on process technology with a goal of reducing manufacturing costs while improving product quality and reliability. The COE also maintains a goal of development and implementation of environmentally benign energetics manufacturing processes.

Point of Contact:
Mr. John Brough
Energetics Manufacturing Technology Center
Indian Head Division
Naval Surface Warfare Center
Indian Head, MD 20640-5035
(301) 743-4417
DSN: 354-4417
FAX: (301) 743-4187
mt@command.nosih.sea06.navy.mil

Manufacturing Science and Advanced Materials Processing Institute

The Manufacturing Science and Advanced Materials Processing Institute (MS&AMPI) is comprised of three centers including the National Center for Advanced Drivetrain Technologies (NCADT), The Surface Engineering Manufacturing Technology Center (SEMTC), and the Laser Applications Research Center (LaserARC). These centers are located at The Pennsylvania State University's Applied Research Laboratory. Each center is highlighted below.

Point of Contact for MS&AMPI:
Mr. Henry Watson
Manufacturing Science and Advanced Materials Processing Institute
ARL Penn State
P.O. Box 30
State College, PA 16804-0030
(814) 865-6345
FAX: (814) 863-1183
hew2@psu.edu

- **National Center for Advanced Drivetrain Technologies**
  The NCADT supports DoD by strengthening, revitalizing, and enhancing the technological capabilities of the U.S. gear and transmission industry. It provides a site for neutral testing to verify accuracy and performance of gear and transmission components.

  Point of Contact for NCADT:
  Dr. Suren Rao
  NCADT/Drivetrain Center
  ARL Penn State
  P.O. Box 30
  State College, PA 16804-0030
  (814) 865-3537
  FAX: (814) 863-6185
  http://www.arl.psu.edu/drivetrain_center.html/

- **Surface Engineering Manufacturing Technology Center**
  The SEMTC enables technology development in surface engineering—the systematic and rational modification of material surfaces to provide desirable material characteristics and performance. This can be implemented for complex optical, electrical, chemical, and mechanical functions or products that affect the cost, operation, maintainability, and reliability of weapon systems.

  Point of Contact for SEMTC:
  Dr. Maurice F. Amateau
  SEMTC/Surface Engineering Center
  P.O. Box 30
  State College, PA 16804-0030
  (814) 863-4214
  FAX: (814) 863-0006
  http://www/arl.psu.edu/divisions/arl_org.html

- **Laser Applications Research Center**

  The LaserARC is established to expand the technical capabilities of DOD by providing access to high-power industrial lasers for advanced material processing applications. LaserARC offers basic and applied research in laser-material interaction, process development, sensor technologies, and corresponding demonstrations of developed applications.

  Point of Contact for LaserARC:
  Mr. Paul Denney
  Laser Center
  ARL Penn State
  P.O. Box 30
  State College, PA 16804-0030
  (814) 865-2934
  FAX: (814) 863-1183
  http://www/arl.psu.edu/divisions/arl_org.html

Gulf Coast Region Maritime Technology Center

The Gulf Coast Region Maritime Technology Center (GCRMTC) is located at the University of New Orleans and will focus primarily on product developments in support of the U.S. shipbuilding industry. A sister site at Lamar University in Orange, Texas will focus on process improvements.

Point of Contact:
Dr. John Crisp
Gulf Coast Region Maritime Technology Center
University of New Orleans
Room N-212
New Orleans, LA 70148
(504) 286-3871
FAX: (504) 286-3898

Appendix G
Completed Surveys

As of this publication, 92 surveys have been conducted and published by BMP at the companies listed below. Copies of older survey reports may be obtained through DTIC or by accessing the BMPnet. Requests for copies of recent survey reports or inquiries regarding the BMPnet may be directed to:

Best Manufacturing Practices Program
4321 Hartwick Rd., Suite 400
College Park, MD 20740
Attn: Mr. Ernie Renner, Director
Telephone: 1-800-789-4267
FAX: (301) 403-8180
ernie@bmpcoe.org

1985	Litton Guidance & Control Systems Division - Woodland Hills, CA
1986	Honeywell, Incorporated Undersea Systems Division - Hopkins, MN (Alliant TechSystems, Inc.) Texas Instruments Defense Systems & Electronics Group - Lewisville, TX General Dynamics Pomona Division - Pomona, CA Harris Corporation Government Support Systems Division - Syosset, NY IBM Corporation Federal Systems Division - Owego, NY Control Data Corporation Government Systems Division - Minneapolis, MN
1987	Hughes Aircraft Company Radar Systems Group - Los Angeles, CA ITT Avionics Division - Clifton, NJ Rockwell International Corporation Collins Defense Communications - Cedar Rapids, IA UNISYS Computer Systems Division - St. Paul, MN (Paramax)
1988	Motorola Government Electronics Group - Scottsdale, AZ General Dynamics Fort Worth Division - Fort Worth, TX Texas Instruments Defense Systems & Electronics Group - Dallas, TX Hughes Aircraft Company Missile Systems Group - Tucson, AZ Bell Helicopter Textron, Inc. - Fort Worth, TX Litton Data Systems Division - Van Nuys, CA GTE C^3 Systems Sector - Needham Heights, MA
1989	McDonnell-Douglas Corporation McDonnell Aircraft Company - St. Louis, MO Northrop Corporation Aircraft Division - Hawthorne, CA Litton Applied Technology Division - San Jose, CA Litton Amecom Division - College Park, MD Standard Industries - LaMirada, CA Engineered Circuit Research, Incorporated - Milpitas, CA Teledyne Industries Incorporated Electronics Division - Newbury Park, CA Lockheed Aeronautical Systems Company - Marietta, GA Lockheed Corporation Missile Systems Division - Sunnyvale, CA Westinghouse Electronic Systems Group - Baltimore, MD General Electric Naval & Drive Turbine Systems - Fitchburg, MA Rockwell International Corporation Autonetics Electronics Systems - Anaheim, CA TRICOR Systems, Incorporated - Elgin, IL
1990	Hughes Aircraft Company Ground Systems Group - Fullerton, CA TRW Military Electronics and Avionics Division - San Diego, CA MechTronics of Arizona, Inc. - Phoenix, AZ Boeing Aerospace & Electronics - Corinth, TX Technology Matrix Consortium - Traverse City, MI Textron Lycoming - Stratford, CT

1991	*Resurvey of Litton Guidance & Control Systems Division* - Woodland Hills, CA Norden Systems, Inc. - Norwalk, CT Naval Avionics Center - Indianapolis, IN United Electric Controls - Watertown, MA Kurt Manufacturing Co. - Minneapolis, MN MagneTek Defense Systems - Anaheim, CA Raytheon Missile Systems Division - Andover, MA AT&T Federal Systems Advanced Technologies and AT&T Bell Laboratories - Greensboro, NC and Whippany, NJ *Resurvey of Texas Instruments Defense Systems & Electronics Group* - Lewisville, TX
1992	Tandem Computers - Cupertino, CA Charleston Naval Shipyard - Charleston, SC Conax Florida Corporation - St. Petersburg, FL Texas Instruments Semiconductor Group Military Products - Midland, TX Hewlett-Packard Palo Alto Fabrication Center - Palo Alto, CA Watervliet U.S. Army Arsenal - Watervliet, NY Digital Equipment Company Enclosures Business - Westfield, MA and Maynard, MA Computing Devices International - Minneapolis, MN *(Resurvey of Control Data Corporation Government Systems Division)* Naval Aviation Depot Naval Air Station - Pensacola, FL
1993	NASA Marshall Space Flight Center - Huntsville, AL Naval Aviation Depot Naval Air Station - Jacksonville, FL Department of Energy Oak Ridge Facilities (Operated by Martin Marietta Energy Systems, Inc.) - Oak Ridge, TN McDonnell Douglas Aerospace - Huntington Beach, CA Crane Division Naval Surface Warfare Center - Crane, IN and Louisville, KY Philadelphia Naval Shipyard - Philadelphia, PA R. J. Reynolds Tobacco Company - Winston-Salem, NC Crystal Gateway Marriott Hotel - Arlington, VA Hamilton Standard Electronic Manufacturing Facility - Farmington, CT Alpha Industries, Inc. - Methuen, MA
1994	Harris Semiconductor - Melbourne, FL United Defense, L.P. Ground Systems Division - San Jose, CA Naval Undersea Warfare Center Division Keyport - Keyport, WA Mason & Hanger - Silas Mason Co., Inc. - Middletown, IA Kaiser Electronics - San Jose, CA U.S. Army Combat Systems Test Activity - Aberdeen, MD Stafford County Public Schools - Stafford County, VA
1995	Sandia National Laboratories - Albuquerque, NM Rockwell Defense Electronics Collins Avionics & Communications Division - Cedar Rapids, IA *(Resurvey of Rockwell International Corporation Collins Defense Communications)* Lockheed Martin Electronics & Missiles - Orlando, FL McDonnell Douglas Aerospace (St. Louis) - St. Louis, MO *(Resurvey of McDonnell-Douglas Corporation McDonnell Aircraft Company)* Dayton Parts, Inc. - Harrisburg, PA Wainwright Industries - St. Peters, MO Lockheed Martin Tactical Aircraft Systems - Fort Worth, TX *(Resurvey of General Dynamics Fort Worth Division)* Lockheed Martin Government Electronic Systems - Moorestown, NJ Sacramento Manufacturing and Services Division - Sacramento, CA JLG Industries, Inc. - McConnellsburg, PA
1996	City of Chattanooga - Chattanooga, TN Mason & Hanger Corporation - Pantex Plant - Amarillo, TX Nascote Industries, Inc. - Nashville, IL Weirton Steel Corporation - Weirton, WV NASA Kennedy Space Center - Cape Canaveral, FL Department of Energy, Oak Ridge Operations - Oak Ridge, TN

1997	Headquarters, U.S. Army Industrial Operations Command - Rock Island, IL SAE International and Performance Review Institute - Warrendale, PA Polaroid Corporation - Waltham, MA Cincinnati Milacron, Inc. - Cincinnati, OH